WALSCHAERT VALVE GEAR

(PART 2)

Serial 4003B — Edition 1

ARRANGEMENT AND OPERATION
(Continued)

DETAILS OF GEAR

GEAR FRAME

1. Purpose.—The purpose of the gear frame is to carry or support the link and one end of the reverse shaft. The gear frame is sometimes called the *link support.*

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2. Reason for Different Types.—Gear frames are of two general types. The gear frame *16,* Fig. 1, is generally used with freight locomotives. With these locomotives, on account of the wheel arrangement, the guide yoke *e* has to be located between the first and second driving wheels in order to connect to the frame, and when so placed it provides a support for the gear frame at a point that permits a proper design of gear.

In Fig. 2, with a passenger locomotive, the guide yoke *e* has to be placed about forward of the first driving wheel in order to connect to the frame, and this brings the type of gear frame shown in Fig. 1 too close to the valve to permit a valve gear of proper design. Therefore, the link has to be placed farther to the rear, and hence the type of gear frame shown in Fig. 2 is used.

3. Construction.—The gear frame *16,* Fig. 1, is a steel casting bolted to the guide yoke *e,* or it may be cast in one piece

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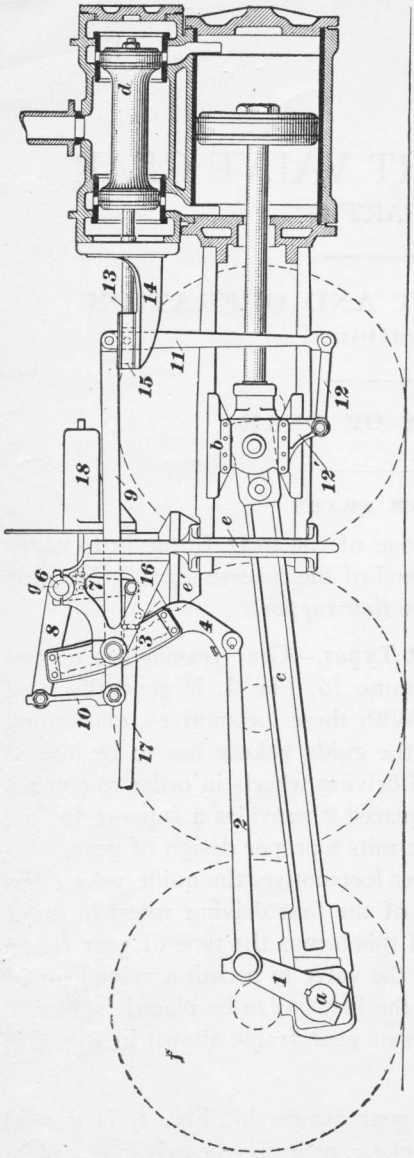

Fig. 1

with the yoke. The upper end of the guide yoke is rectangular as shown and extends across the frames to the other side where the arrangement of guide bars and gear frame is the same. The guide yoke is connected to the frame by knees, or brackets, *e'*. The construction of the type of gear frame shown in Fig. *2* varies to such an extent that it is impossible to cover all the designs. Therefore, only two fairly representative designs will be considered.

In Fig. *2* the frame consists of two link supports *19* between which the link swings, each support being provided with a bearing in which the link trunnions turn. The front ends of the link supports are bolted to the part of the guide yoke *e* that extends across the frames, and the back ends are bolted to a cross-tie or cross-bearer *20*. The guide yoke and the cross-tie are connected to the frame by knees, or

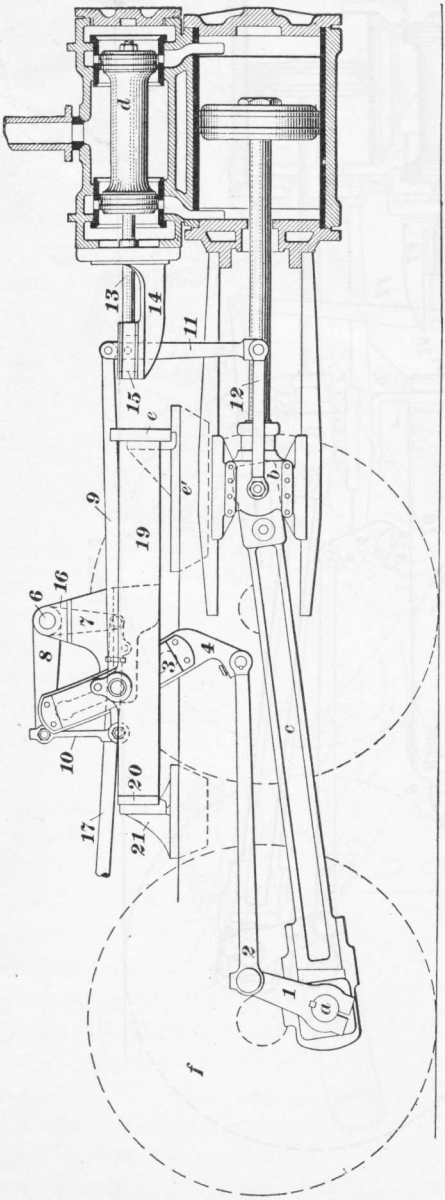

FIG. 2

brackets, *e'* and *21*. The reverse shaft is carried in a bracket *16* which is bolted to the inside link support *19*.

4. In Fig. 3 is shown a gear frame of one-piece construction. With this design the two side pieces *16* are welded to end pieces, the whole frame forming a single rectangular part. The front end of the frame is bolted to the part p_1 of the guide yoke *r* that extends across the frames to the other side of the locomotive and supports the front end of the gear frame on the other side. The rear end of the frame is bolted to the cross-bearer *p*, which also extends across the engine and supports the rear end of the gear frame on the other side. The cross-bearer and the guide yoke are connected to each of the side frames by knees, or brackets, *q* and q_1.

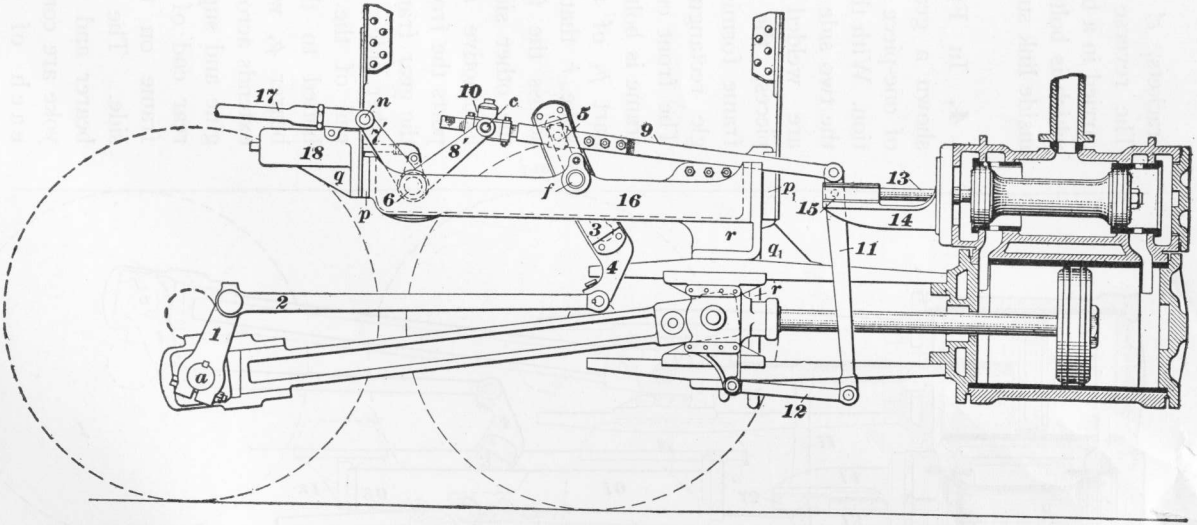

FIG. 3

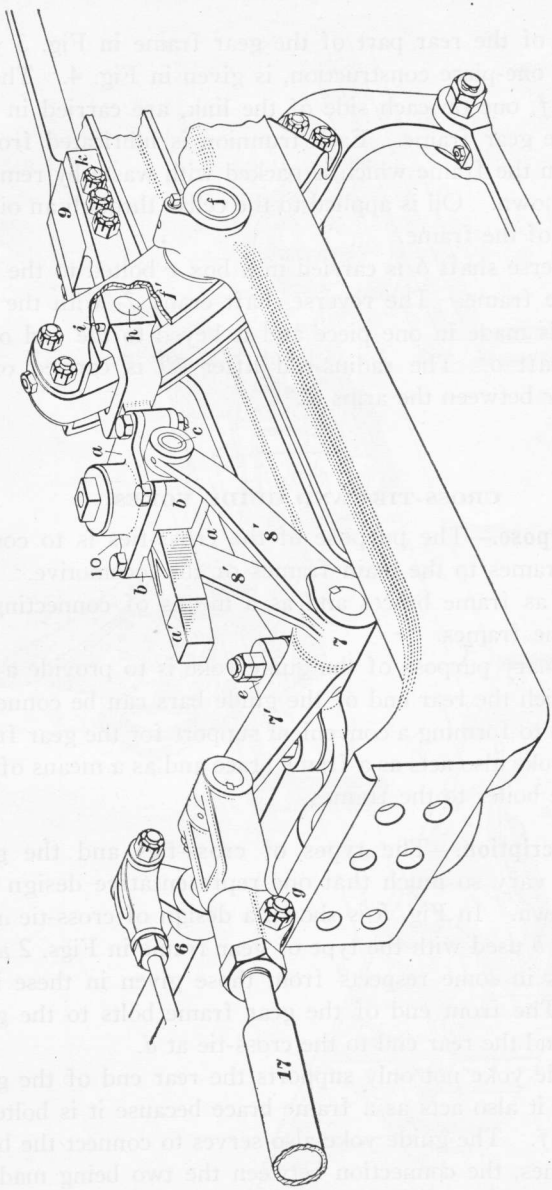

FIG. 4

A view of the rear part of the gear frame in Fig. 3 which shows the one-piece construction, is given in Fig. 4. The link trunnions *f*, one on each side of the link, are carried in bearings in the gear frame. Each trunnion is lubricated from an oil cellar in the frame which is packed with waste by removing the plug shown. Oil is applied to the cellar through an oil hole in the top of the frame.

The reverse shaft *6* is carried in a box *e* bolted to the inner side of the frame. The reverse-shaft crank *7*, with the arms *7'* and *8'* is made in one piece and is keyed to the end of the reverse shaft *6*. The radius-rod lifter *10* is carried on the trunnions *c* between the arms *8'*.

CROSS-TIES AND GUIDE YOKES

5. Purpose.—The purpose of the cross-ties is to connect the gear frames to the main frames of the locomotive. They also serve as frame braces and as a means of connecting the boiler to the frames.

The primary purpose of the guide yoke is to provide a rigid part to which the rear end of the guide bars can be connected. In addition to forming a convenient support for the gear frame, the guide yoke also acts as a frame brace and as a means of connecting the boiler to the frames.

6. Description.—The types of cross-ties and the guide yoke used vary so much that one representative design only will be shown. In Fig. 5 is shown a design of cross-tie *a* and guide yoke *b* used with the type of gear frame in Figs. 2 and 3 that differs in some respects from those given in these illustrations. The front end of the gear frame bolts to the guide yoke at *c* and the rear end to the cross-tie at *d*.

The guide yoke not only supports the rear end of the guide bars *e*, but it also acts as a frame brace because it is bolted to the frames *f*. The guide yoke also serves to connect the boiler to the frames, the connection between the two being made by the waist sheets *g*, which are bolted at their upper ends to the boiler angle pieces *h*. The cross-tie *a* in addition to supporting

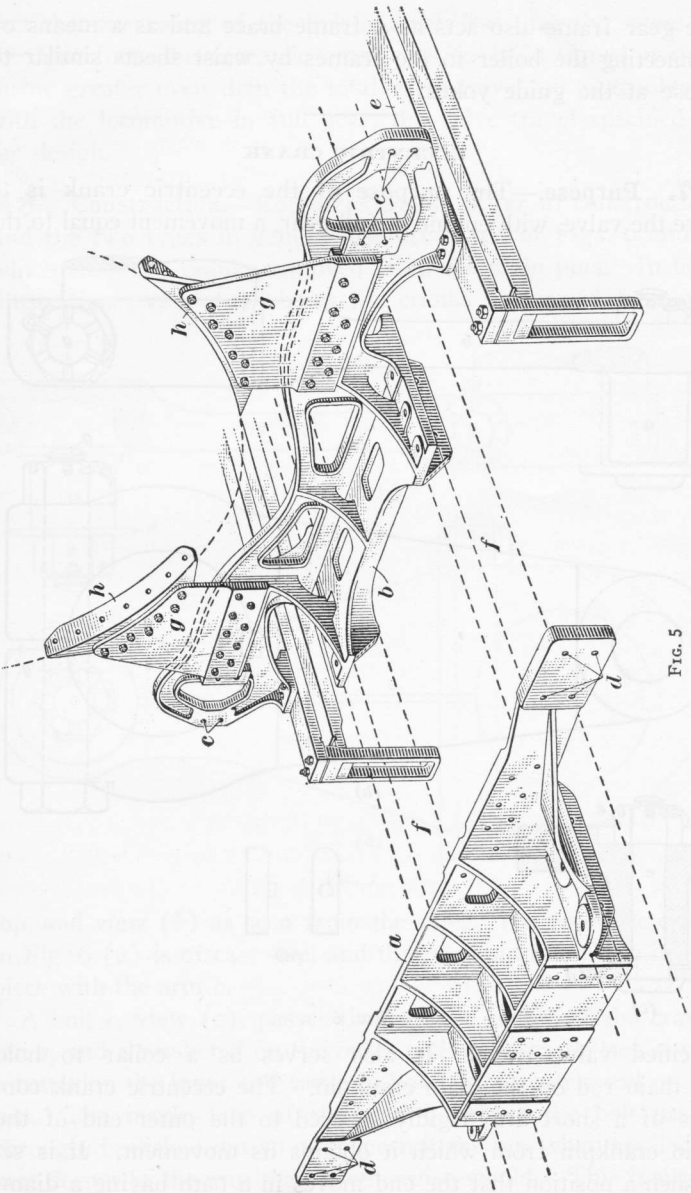

FIG. 5

the gear frame also acts as a frame brace and as a means of connecting the boiler to the frames by waist sheets similar to those at the guide yokes.

ECCENTRIC CRANK

7. Purpose.—The purpose of the eccentric crank is to give the valve, with engine in full gear, a movement equal to the

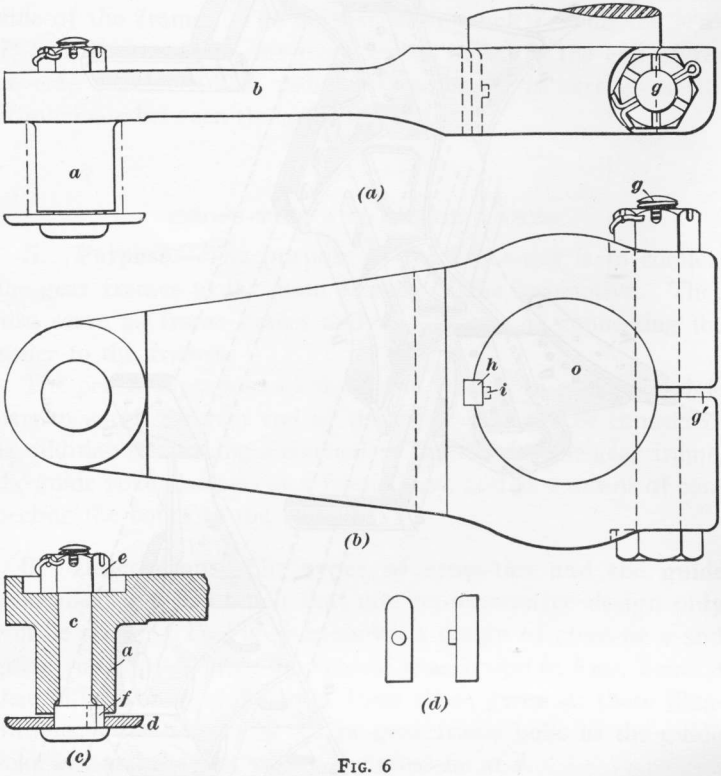

FIG. 6

specified valve travel. It also serves as a collar to hold the main rod on the main crankpin. The eccentric crank consists of a short arm rigidly secured to the outer end of the main crankpin from which it obtains its movement. It is set in such a position that the end moves in a path having a diameter smaller than that of the main pin. Due largely to the

fact that the swing of the link is much less than the swing of the link foot, the eccentric crank has to be designed with a throw greater even than the total valve travel, so as to obtain, with the locomotive in full gear, the valve travel specified in the design.

8. Construction.—Eccentric cranks differ in construction, and the two types in general use are given in Figs. 6 and 7, which show the cranks removed from the main pins. In both illustrations, view (*a*) shows the cranks as viewed from the

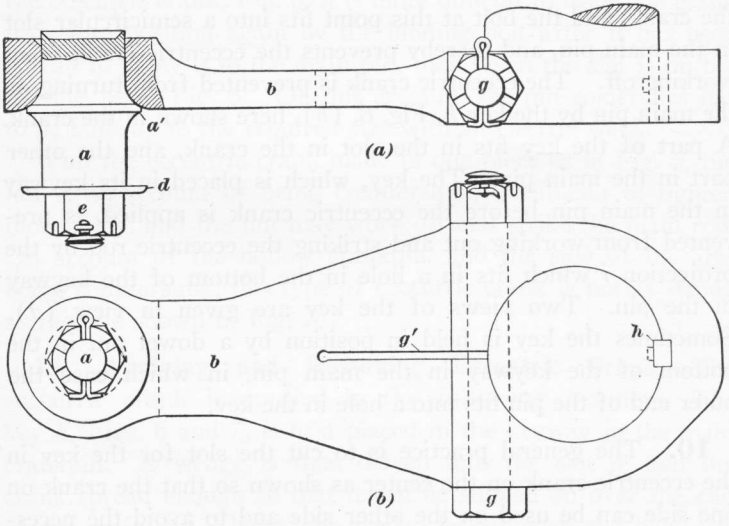

FIG. 7

top, and view (*b*) as seen from the side. The eccentric crank in Fig. 6 (*a*) is of cast steel and the crankpin *a* is made in one piece with the arm *b*.

A bolt *c*, view (*c*), passes through the center of the crankpin *a*, and a washer *d* on the outer end and a castle nut *e* with a cotter on the inner end serve to hold the eccentric rod on the pin. The inside face of the arm *b*, where the bolt passes through, is dished out so as to permit the nut when applied to seat deeper in the arm than it otherwise would. This is necessary in order to have the nut clear the main rod. The bolt *c*

is prevented from turning when applying or removing the nut, by a square key *f*, which fits in a slot in the bolt *c*, the washer *d*, and the pin *a*.

9. The eccentric crank is held on the end of the main pin by the binding bolt *g* and a nut, views (*a*) and (*b*), Figs. 6 and 7. A slot *g'* ¼ inch wide is cut from the end of the crank into the opening *o* for the main crankpin. When the nut on the bolt *g* is tightened up, the width of the slot is reduced and the eccentric crank is clamped on the pin. A part of the middle section of the bolt *g* extends into the circular opening *o* in the crank, and the bolt at this point fits into a semicircular slot in the main pin, and thereby prevents the eccentric crank from working off. The eccentric crank is prevented from turning on the main pin by the key *h*, Fig. 6, (*b*), here shown in the crank. A part of the key fits in the slot in the crank, and the other part in the main pin. The key, which is placed in its keyway in the main pin before the eccentric crank is applied, is prevented from working out and striking the eccentric rod by the projection *i* which fits in a hole in the bottom of the keyway in the pin. Two views of the key are given in view (*d*). Sometimes the key is held in position by a dowel pin in the bottom of the keyway in the main pin, in which case the outer end of the pin fits into a hole in the key.

10. The general practice is to cut the slot for the key in the eccentric crank on the center as shown so that the crank on one side can be used on the other side and to avoid the necessity of carrying right and left cranks in stock. A crank must be turned over when taken from one side of the engine to the other and the slot when cut in the center comes in the same place on the other pin.

In Fig. 7 the crankpin *a* is made separate from the arm *b*, and is pressed into it until a shoulder *a'* on the pin strikes the side of the arm. The inner end of the crankpin now projects about ¼ inch beyond the other side of the arm as shown, this allowance being provided for riveting over. The side of the arm is countersunk as shown and the end of the pin when riveted over is flush with the side of the arm. The outer end of

the pin *a* is turned to a smaller diameter than the pin proper and is threaded for the castle nut *e*. The eccentric rod is held on the pin by the nut which is prevented from coming off by a cotter key, and by the washer *d*.

The main crankpin end of the crank differs from that shown in Fig. 6, in that the positions of the slot *g'* and the keyway have been reversed. This arrangement brings the binding bolt *g* in front of the main crankpin. The eccentric crank is prevented from turning on the axle by the same type of key *h* as shown in Fig. 6 (*b*). With the slot between the ends of the eccentric crank, Fig. 6, it is more difficult to draw the crank back into position again by the binding bolt after it has been spread to apply it to the main pin, than when the slot is on the outside, as in Fig. 6. On this account, the pin sometimes has to be built up to the required size with an electric weld.

With the eccentric crank made in one piece as in Fig. 6, the nut *e*, on account of being countersunk, is difficult to tighten thoroughly, and the nut may work off and strike the main rod. On account of the hollow crankpin, and the side of the arm being countersunk, this type of eccentric crank is not as strong as the one shown in Fig. 7.

11. Applying and Removing Eccentric Crank.—The eccentric crank is applied in the following manner: The key *h*, Figs. 6 and 7, is first placed in the keyway in the main crankpin. A wedge is then driven into the slot *g'* and the crank spread enough so that it can be slipped on over the end of the main pin. Next, the wedge is removed, the bolt *g* is driven through and the nut and cotter key are applied.

The eccentric crank is removed by driving out the bolt *g*, then driving a wedge in the slot *g'*, and prying the crank off. The end of the main pin on which the eccentric crank is placed, may be either tapered or straight; a tapered pin makes the crank easier to remove.

ECCENTRIC ROD

12. Purpose.—The purpose of the eccentric rod is to transmit the movement of the eccentric crank to the link.

13. Construction.—A top view of an eccentric rod is shown in Fig. 8 (*a*). View (*b*) shows the rod as viewed from the side and views (*c*), (*d*), and (*e*) show the eccentric-rod pin. A solid brass bush *a* about $\frac{1}{2}$ inch thick is pressed into

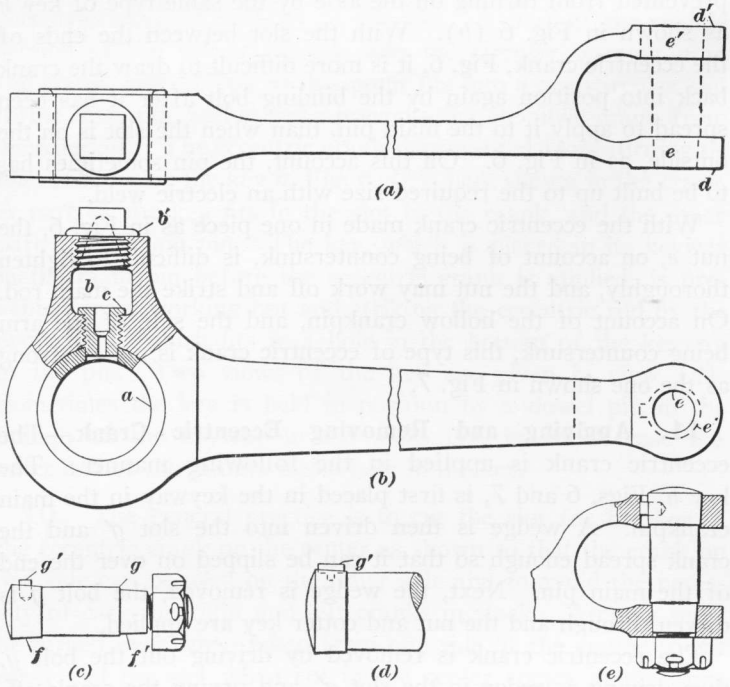

FIG. 8

the back end of the rod where it fits on the eccentric crankpin. The bushing is pressed out and renewed when it becomes worn. This end of the rod has a grease cellar *b*, the upper end of which is normally closed by a grease plug *b'*. The bottom of the grease collar is provided with a hollow steel plug *c* which is screwed into the bottom of the cellar and extends nearly to the wearing surface of the brass bushing. The plug provides

a means by which the grease from the cellar is applied to the eccentric crankpin when the grease plug is screwed down, and it also prevents the bushing from turning. The front end of the eccentric rod, view (*a*) is forked and when the rod is connected up, the link foot is placed between the two jaws *d* and *d'*. The holes *e* and *e'* in each jaw for the eccentric-rod pin are tapered toward the outside of the rod and are shown by dash lines as they cannot be seen when viewed from the top. The position of the pin between the jaws is shown by broken lines. The jaws are usually made about $\frac{1}{16}$ inch wider than the link foot.

14. The fact that the holes in the rod are tapered is also shown in Fig. 8 (*b*), in which the larger hole *e'* is dotted in, thereby indicating that this hole is in the inside jaw and cannot be seen when the rod is viewed from the outside. The eccentric-rod pin, view (*c*), which serves to connect the eccentric rod to the link foot, is case-hardened, and as the pin holes are tapered toward the outside the pin has to be applied from the inside of the rod, and this fact makes it more convenient to drive out, as well as to apply, the nuts. The ends *f* and *f'* of the pin, which come in the jaws of the rod, are tapered to fit the taper of the holes, and the portion between the jaws is straight. The tapered ends permit the pin to be easily driven out, as the slightest movement loosens it. The pin has a shoulder at *g*, which prevents the jaws of the rod from being cramped on the link foot when the castle nut on the pin is tightened up. A dowel pin *g'* about $\frac{3}{8}$ inch square is driven into the side of the pin and fits into a slot in the side of the rod when the pin is applied.

15. The dowel pin serves two purposes; it prevents the pin from turning when the nut is being applied or removed, and it keeps the pin from turning when the engine is moving, and thereby confines the wearing surface to the portion between the jaws and not to the whole pin, as would be the case if it could turn. As the pin does not turn, no bushings are required in the holes in the rod. Sometimes the pin is prevented from turning by a key and a dowel pin made in one piece, as shown

in detail in view (*d*), Fig. 8. This arrangement offers more resistance to shearing off than the plain dowel pin, as the key extends into the side of the head of the pin. The pin is lubricated from an oil cellar in the link foot packed with waste or hair. This cellar, as well as others in the gear, is usually packed with hair in the winter and with waste in the summer. Waste hardens in cold weather, and prevents oil from reaching the pin, while hair permits the oil to feed too rapidly in the summer.

The eccentric-rod pin is shown applied to the rod in view (*e*) in which two nuts and a cotter key are used to prevent the pin from coming out. The eccentric rod is made as long as possible because the irregularities due to the angularity of the rod are less when the rod is long than when it is short.

PURPOSE AND CONSTRUCTION OF LINK

16. Purpose.—The purpose of the link is to transmit the movement of the eccentric crank and the eccentric rod to the radius rod. It also permits the locomotive to be reversed and the cut-off changed.

17. Construction.—The construction of the link used with the Walschaert valve gear will be explained by referring to Fig. 9 in which (*a*) is a side view of the link; (*b*) a rear view, and (*c*) a side view of the center piece or slotted part of the link. The link is usually made in three parts, the two cheek pieces or bracket pieces *a*, one on each side, view (*b*), including the fulcrum pins or link trunnions *b* by means of which the link is carried in the gear frame and a center piece *c* with a slot *c'*, view (*c*), in which the link block operates. The entire link is case-hardened.

18. The purpose of the bracket pieces *a*, view (*b*), Fig. 9, is to connect the fulcrum pins or link trunnions to the center piece *c* in such a way as to permit the radius rod to move the link block up and down in the slot in the center piece. Therefore, the bracket pieces, view (*b*), must be bolted to the ends of the center piece because, if bolted to the middle,

the radius rod could not move the link block past the center of the link. Then, too, the bracket pieces must be made so that they stand away from the center piece, except at the ends, and thereby leave a space d about $1\frac{9}{16}$ inches in width on each side for the forked end of the radius rod. The slotted

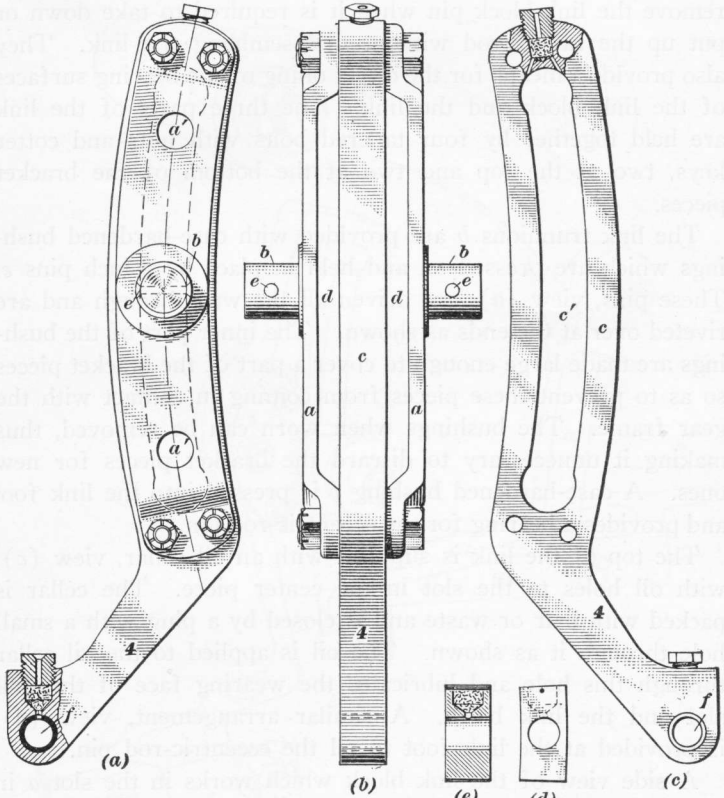

FIG. 9

center piece merely forms a guide for the link block when the radius rod is moved by the reverse lever. The center piece is extended down much farther than the bracket pieces so as to bring the eccentric-rod connection at the lower end as near as possible to the horizontal line through the center of the main driver and the center of the cylinder. The lower portion *4*

of the center piece is referred to as the *link foot,* which is sometimes made separate and bolted to the center piece instead of being made in one piece with it.

19. Each of the bracket pieces, Fig. 9 (*a*), has a circular opening *a'* at the top and bottom. These openings are used to remove the link-block pin when it is required to take down or put up the radius rod without disassembling the link. They also provide a means for the direct oiling of the bearing surfaces of the link block and the link. The three parts of the link are held together by four tapered bolts with nuts and cotter keys, two at the top and two at the bottom of the bracket pieces.

The link trunnions *b* are provided with case-hardened bushings which are pressed on and held in place by $\frac{5}{8}$-inch pins *e.* These pins, view (*a*), are driven all the way through and are riveted over at the ends as shown. The inner part of the bushings are made large enough to cover a part of the bracket pieces so as to prevent these pieces from coming in contact with the gear frame. The bushings when worn can be removed, thus making it unnecessary to discard the bracket pieces for new ones. A case-hardened bushing *f* is pressed into the link foot and provides a bearing for the eccentric-rod pin.

The top of the link is supplied with an oil cellar, view (*c*), with oil holes to the slot in the center piece. The cellar is packed with hair or waste and is closed by a plug with a small hole through it as shown. The oil is applied to the oil cellar through this hole and lubricates the wearing face of the link slot and the link block. A similar arrangement, view (*a*), is provided at the link foot to oil the eccentric-rod pin.

A side view of the link block which works in the slot *a* in the center piece is given in view (*d*), and view (*e*) shows a section through the center of the block. This part will be described more fully later.

20. One-Piece Link.—A view of a one-piece link used on the Pennsylvania Railroad is shown in Fig. 10. The link is carried in the gear frame on the trunnions *a* which are made in one piece with the two bracket pieces *b,* one on each side

of the link and connected to the back of it by three bolts. As shown, the distance between each inside face of the jaw of the bracket pieces and the nearest sides of the link is sufficient to permit the radius rod *c* to move the link block *d* from one end of the link to the other. The radius-rod hanger *10* is

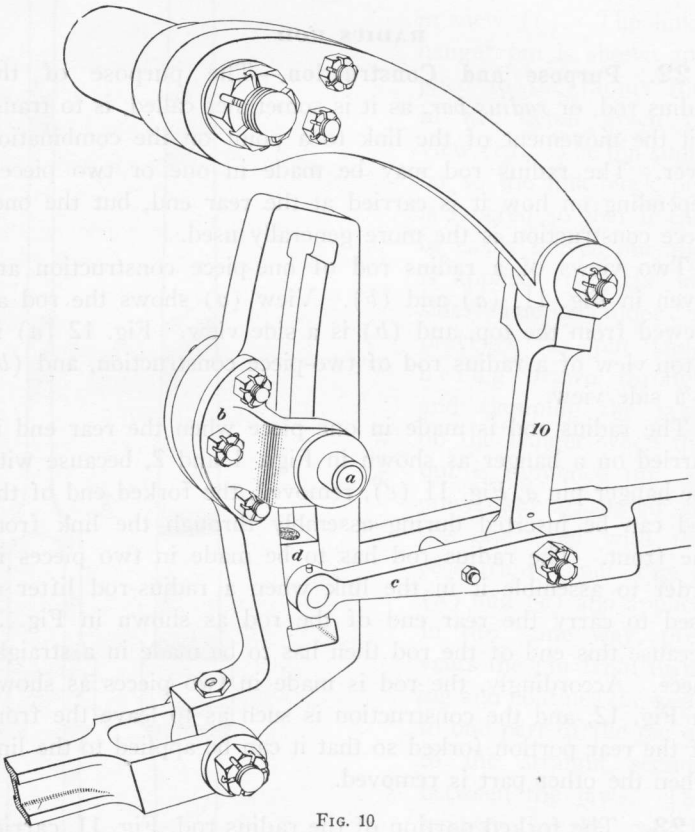

FIG. 10

connected to the radius rod in front of the link because the bracket piece *b* would interfere with the movement of the rod were it extended to the rear of the link.

21. Dimensions of Link.—The total length of the link is about 3½ feet, the width of a bracket piece, measured on the

side is about 5 inches, and when measured at the rear about $1\frac{1}{2}$ inches. The center piece is about $2\frac{1}{2}$ inches wide and the total width of the link is about $6\frac{1}{2}$ inches. The link trunnions are usually about 3 inches in diameter, and the length of the link slot is about 22 inches.

RADIUS ROD

22. Purpose and Construction.—The purpose of the radius rod, or *radius bar,* as it is sometimes called, is to transmit the movement of the link to a point on the combination lever. The radius rod may be made in one or two pieces, depending on how it is carried at the rear end, but the one-piece construction is the more generally used.

Two views of a radius rod of one-piece construction are given in Fig. 11, (*a*) and (*b*). View (*a*) shows the rod as viewed from the top, and (*b*) is a side view. Fig. 12 (*a*) is a top view of a radius rod of two-piece construction, and (*b*) is a side view.

The radius rod is made in one piece when the rear end is carried on a hanger as shown in Figs. 1 and 2, because with the hanger pin *a,* Fig. 11 (*c*), removed, the forked end of the rod can be inserted during assembly through the link from the front. The radius rod has to be made in two pieces in order to assemble it in the link when a radius-rod lifter is used to carry the rear end of the rod as shown in Fig. 3, because this end of the rod then has to be made in a straight piece. Accordingly, the rod is made in two pieces as shown in Fig. 12, and the construction is such as to leave the front of the rear portion forked so that it can be applied to the link when the other part is removed.

23. The forked portion of the radius rod, Fig. 11, carries two tapered case-hardened pins, the link-block pin *h* indicated by dash lines in view (*a*) and used to connect the link block to the rod, and the link-hanger pin *a,* view (*c*), which connects the rod to the link hanger. The pin holes in the jaws are indicated by dash lines, view (*a*), and they are tapered to conform to the shape of the pins toward the outside face of the rod, hence

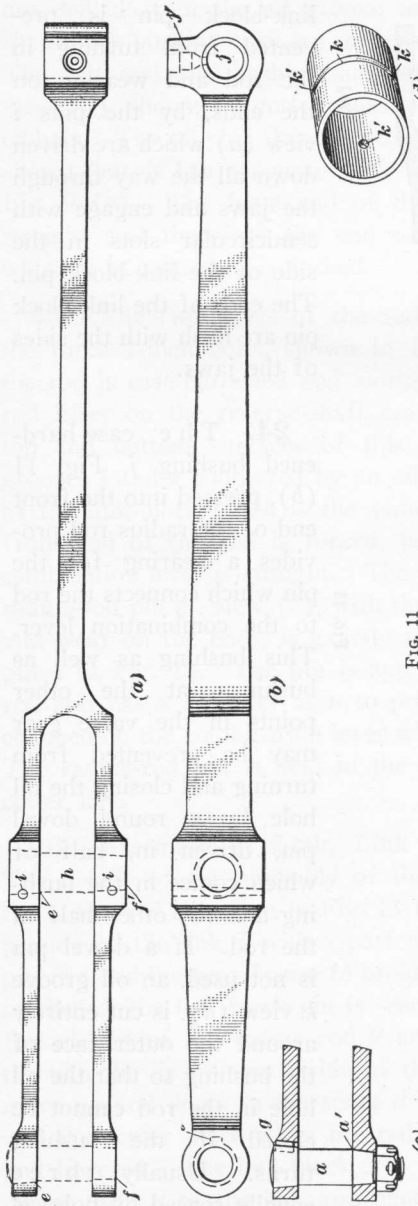

FIG. 11

the holes e and e' in the inside jaw are larger than the holes f and f respectively, in the outside jaw, as shown by the full and dash circles in view (b). The link-hanger pin is shown applied to the radius rod in the detail given in view (c). The pin similar to the link-block pin is tapered so that it can be easily driven out and is applied from the inside. The shoulder a' prevents the pin from being drawn through and clamping the jaws on the hanger when the nut is tightened up. A dowel key g similar to the one used with the eccentric-rod pin, Fig. 8 (d) and (e) and applied in the same way, prevents the pin from turning and confines the wear to one part of the pin or to the straight section between the jaws. The keyway in the rod is shown at g', Fig. 11 (b). The hanger pin is held in the rod by a castle, or turret, nut which is prevented from coming off by a cotter key. The

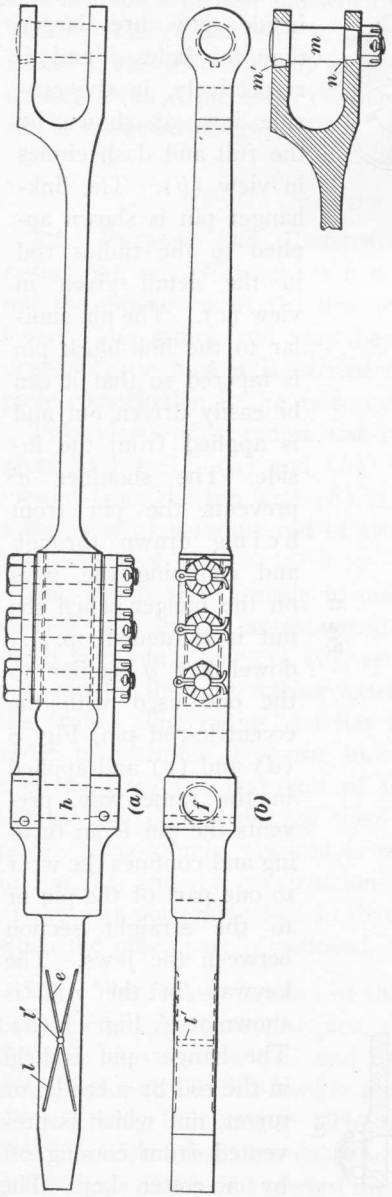

FIG. 12

link-block pin is prevented from turning in the rod and wearing on the ends, by the pins *i* view (*a*) which are driven down all the way through the jaws and engage with semicircular slots in the side of the link-block pin. The ends of the link-block pin are flush with the sides of the jaws.

24. The case-hardened bushing *j*, Fig. 11 (*b*), pressed into the front end of the radius rod provides a bearing for the pin which connects the rod to the combination lever. This bushing as well as bushings at the other points in the valve gear may be prevented from turning and closing the oil hole by a round dowel pin, driven in, half of which comes in the bushing and the other half in the rod. If a dowel pin is not used, an oil groove *k* view (*d*), is cut entirely around the outer face of the bushing so that the oil hole in the rod cannot be closed if the bushing turns. Usually three equally spaced oil holes *k'*

are drilled from the oil groove to the bearing face so that, should the bushing turn, an oil hole will always be uppermost. The pin and the bushing are lubricated from a cellar *j'*, view (*b*), shown by dotted lines, which is packed with waste or hair. The oil plug through which the cellar is packed is not shown, but it has a countersunk hole for applying oil, as in Fig. 9 (*a*). The front end of the radius rod in Fig. 11 is straight and therefore the end of the combination lever to which it is connected is forked.

25. The two parts of the radius rod are connected by the three 1-inch bolts, shown in Fig. 12. The rear end of the rod is case-hardened and works in a slip block or radius-rod lifter on the reverse-shaft crank shown in Fig. 3. The top and bottom surfaces of this part of the rod have oil grooves *l* and *e* connected by an oil hole *l'*. The arrangement of the link-block pin *h* is the same as in Fig. 11 (*a*). The front end of the rod is forked, hence the upper end of the combination lever is straight. The arrangement of the tapered radius-rod pin *m*, view (*c*), with the key *m'* to prevent turning and wear on the ends, is exactly the same as the link-hanger pin *a* in Fig. 11. The pin is applied from the inside of the rod and has a shoulder at *n* to prevent the jaws from being clamped on the combination lever when the nut is tightened up. The radius-rod pin is held in the rod by a castle nut and a cotter key.

26. Assembly of Link, Link Block, and Radius Rod. The details of the assembly of the link, the link block, and the radius rod are given in Fig. 13 (*a*), which shows the lower portion of the link *3* with a part of one of the outer bracket pieces *a* and the gear frame *16* broken away. The link block is marked *5*, the link-block pin is seen at *h*, and the jaws of the forked end of the radius rod *9* are indicated by *g* and pass through the link on each side of the center piece *c*; the jaws move up and down in the space *d* between each bracket piece and the center piece when the radius-rod hanger *10* is raised and lowered. The link block *5* is placed in the slot *c'* in the center piece *c* of the link and hence sets between the jaws *g*

of the radius rod. The link-block pin *h* on which the link block turns when the link swings passes entirely through the jaws *g* and the link block, and pins the link block to the radius rod. The purpose of the link block and the link-block pin is to transmit the backward-and-forward movement of the link to the radius rod. The link block also guides the movement of the rear end of the radius rod when it is raised and lowered.

27. The link-block pin is prevented from turning in the jaws of the radius rod and thereby wearing on the ends, as

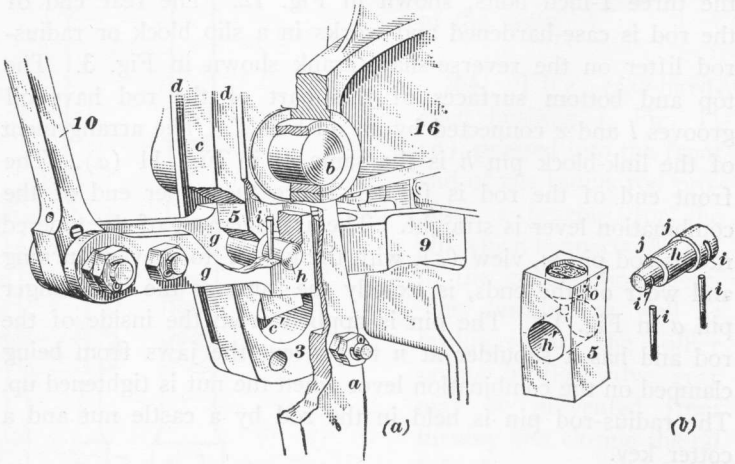

FIG. 13

well as from working out, by a $\frac{5}{8}$-inch pin *i*, Fig. 13, one in each jaw. These pins are usually behind the link-block pin, as shown, so as to make their application easier. They are driven down from the top, and engage semicircular slots *i'*, view (*b*), in the link-block pin where they pass it. With the link-block pin fixed, the wear is confined to the portion on which the link block turns. The pins *i*, view (*a*), are split slightly and then spread at their lower ends after they are applied, to prevent them from working up and out. The link block *5*, the link-block pin *b* and the two pins *i*, are shown removed in view (*b*). The link block is case-hardened and its

wearing surfaces are slightly curved so as to conform to the curvature of the slot *c'*, view (*a*), in the center piece when the block is being raised and lowered. The top of the link block has an oil well packed with waste. The waste retains the oil and permits a slow feed through the small opening shown in the bottom of the well to the link-block pin which passes through the circular opening *h'* in the link block. The oil from the oil well can also pass through the small holes *o* to the front face of the link block. The ends of the link-block pin *h* where they fit in the jaws of the radius rod, are tapered in the same direction or toward the outer face of the rod so that the pin can be easily driven out. The shoulders *j* on the tapered ends limit the distance the pin can be driven into the radius rod. As the link-block pin hole in the inside jaw of the radius rod is larger than the hole in the outer jaw, the pin is driven in from the side of the link next to the boiler and is driven out in the reverse direction.

COMBINATION LEVER

28. Purpose.—The combination lever merely times the valve relative to the piston, thus the valve is timed to give lead opening with the piston at the end of its stroke.

29. Construction.—In Figs. 14 and 15 are shown two views of combination levers used with inside-admission valves, which differ in construction at their upper ends, as one is straight and the other is forked. Views (*a*) show the levers as viewed from the side and views (*b*) as seen from the front.

The radius rod is connected by the radius-rod pin to the top of the lever at *a*, the valve-stem crosshead is connected to the lever by the valve-stem crosshead pin *b*, and the union link is connected to the bottom of the lever at *c*. The only difference between the levers in Figs. 14 and 15 is in the method used in connecting the radius rod to them. In Fig. 14 the top of the rod is straight and this requires the front end of the radius rod to be forked as shown in Fig. 12. In Fig. 14 the upper end of the rod is forked and this requires the front end of the rod to be straight as in Fig. 11. A case-hardened

bushing is pressed into the lever at *a* and *c*, Fig. 14, and at *c*, Fig. 15, as the rod turns on pins at these points. The valve-stem crosshead pin *b* is about $1\frac{3}{4}$ inches in diameter and is held in the lever by a $\frac{1}{2}$-inch tapered pin *b'* which is driven in from the front and is riveted over on the small end. The pin *b'*

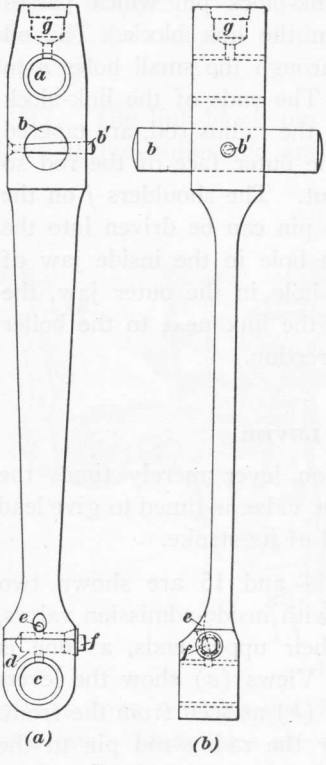

FIG. 14

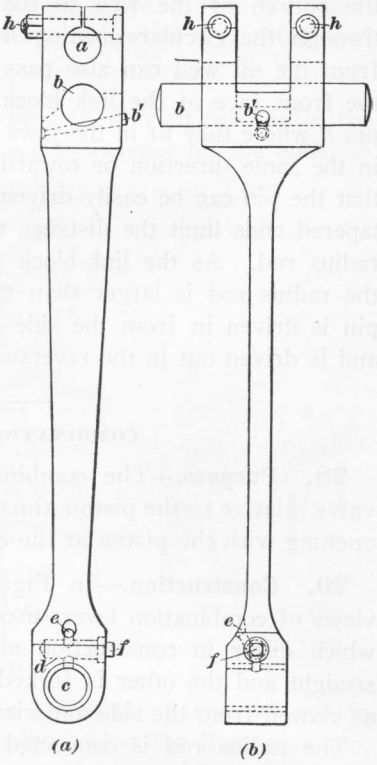

FIG. 15

may pass through the center of the pin *b*, Fig. 14 (*a*), or through the side, Fig. 15 (*a*).

30. The pin connecting the union link to the combination lever at *c*, Figs. 14 and 15, is lubricated from a cavity *d* in the rod, which is provided with an oil hole *e*. The cavity is filled with hair or waste by removing the pipe plug *f*, which is a round plug with a square head. The radius-rod pin at *a*,

Fig. 14, is lubricated in the same way except that the oil hole is in the plug, not shown, which closes the upper end of the waste cavity *g*. The upper end of the lever in Fig. 15 is forked, and this requires the front end of the radius rod to be made straight and supplied with a case-hardened bushing *j*, Fig. 11 (*a*), for the radius-rod pin. The pin which is inserted at *a*, Fig. 15, is prevented from coming out and also from turning by the two binding bolts and nuts *h*. The bolts pass through slots in the side of the pin and draw the slotted upper ends of the lever together and thereby clamp them on the pin. The bushings in the lever may be prevented from turning by dowel pins, or an oil groove may be cut in the bushing so that should they turn, the oil holes in the lever will not be closed.

31. Proportions of Combination Lever.—The length of the piston stroke, the lap and the lead and the total length of the combination lever being given, the proportions of the lever or the distance between the center of the pin holes can be found from the following rule:

Rule.—*To find the short end of the lever or the distance between the center of the radius rod and the valve-stem crosshead pins with an outside-admission valve, multiply the whole length of the lever by twice the lap and the lead and divide by the sum of twice the lap and the lead and the stroke. In the case of an inside-admission valve, multiply the whole length of the lever by twice the lap and the lead, and divide by the stroke. To find the long end of the lever, subtract the length of the short end from the total length.*

EXAMPLE.—The stroke of the piston is 30 inches, twice the lap and lead is $2\frac{1}{2}$ inches, and the length of the combination lever is 36 inches, the valve is of the inside-admission type. What is the length of the short and long arms of the lever?

SOLUTION.—From the rule, the distance between the center of the radius-rod pin and the valve-stem crosshead pin, or the length of the short arm is $\frac{36\times 2\frac{1}{2}}{30}=3$ in. The length of the long arm is $36-3=33$ in. Ans.

When working examples of this kind, $\frac{1}{16}$ inch is usually added to twice the lap and the lead to allow for lost motion in the connections.

COMBINATION, OR UNION, LINK

32. Purpose.—The purpose of the combination, or union, link is to transmit the movement of the crosshead to the lower end of the combination lever. The link is always forked at the front end and may or may not be forked at the back end, depending on whether it is connected to an arm on the crosshead or to the wristpin.

33. Construction.—Two views of the type of union link used when its rear end is connected to the crosshead pin or

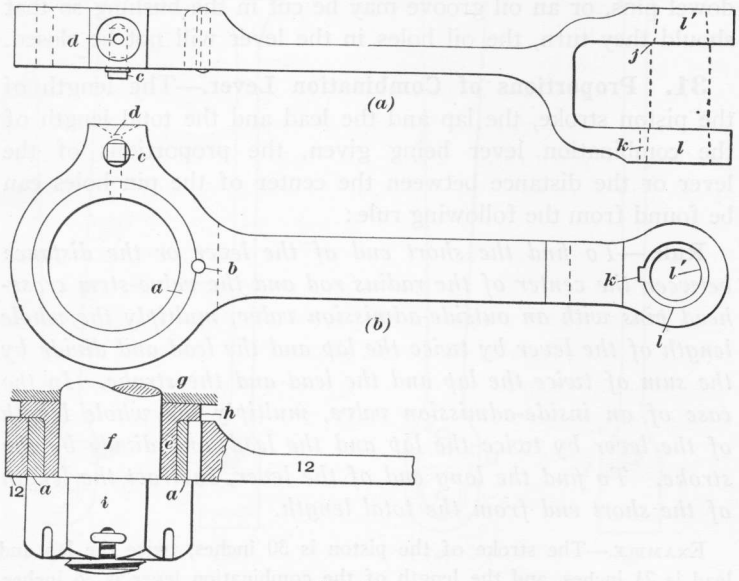

FIG. 16

wristpin, is shown in Fig. 16, in which (*a*) is a top view, and (*b*) a side view. In view (*b*) a case-hardened bushing *a* is pressed into the back end of the rod at the wristpin connection, and is prevented from turning by a round $\frac{3}{8}$-inch pin *b*, driven in. A cellar, which is packed with waste or hair by removing a $\frac{1}{2}$-inch pipe plug *c* in combination with an oil hole *d*, with a countersunk opening, provides for lubrication.

A detail which shows how the back end of the rod is connected to the end of the wristpin is shown in view (*c*). A collar *e* is placed over the end of the wristpin *f*, the inner side of which bears against the side of the crosshead *g*. The rear end of the union link *12* with the bushing *a* turns freely on the collar, and is held between the shoulder *h* on the collar and the nut *i*. The front end of the union link, view (*b*), is forked to receive the lower end of the combination lever.

34. The pin holes *l* and *l'*, Fig. 16, in the jaws are tapered toward the inside jaw, hence the larger hole *l* is in the outside jaw as shown in view (*b*). The ends of the pin are tapered to conform to the pin holes, but as shown by the broken lines, view (*a*), the portion between the jaws is straight. The pin has to be applied from the outside because the piston rod interferes with its application from the inside. The slot in the outside jaw for a dowel key is shown at *k*. The key is similar to the one shown in Fig. 8 (*c*) or (*d*), and is placed on the pin before it is placed in the link. Its purpose is to prevent the pin from turning when the nut is being applied or removed, and, in addition, it holds the pin fixed and thereby confines the wear to the portion between the jaws. The pin is held in position by a castle nut and a cotter key.

When the union link is connected to an arm on the crosshead, the construction at the rear end of the link is the same as at the front end.

RADIUS-ROD HANGER

35. Purpose.—The purpose of the radius-rod hanger *10*, Fig. 2, is to raise or lower the radius rod and link block. The lower end of the hanger is flexibly connected to the radius rod by the radius-rod hanger pin *a*, Fig. 11 (*c*), and the upper end to the reverse-shaft crank or to the reverse-shaft arm, depending on the side of the engine considered.

36. Construction.—A side view of a radius-rod hanger is given in Fig. 17 (*a*), and (*b*) is a front view. As both ends of the hanger turn on pins, a case-hardened bushing *a* is pressed into the lower end of the hanger and a similar one into the

upper end. Oil is applied to the wearing surface of the bushings and the pins from oil cellars *c*, in the top and bottom of

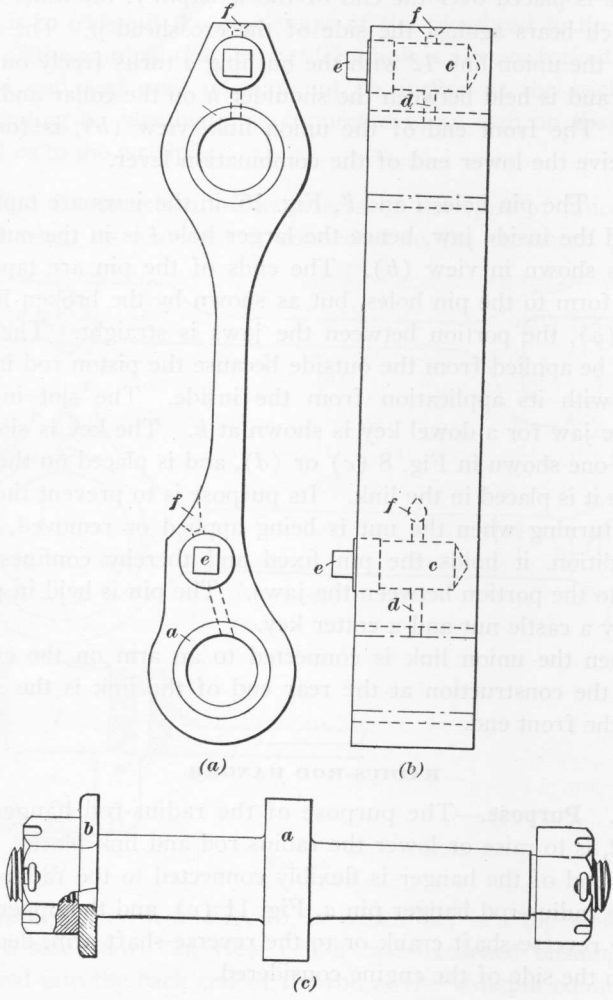

FIG. 17

the hanger, shown by dash lines in view (*b*), and oil holes *d*. The cellars are packed with hair or waste by removing the pipe plugs *e*, and are supplied with oil through the holes *f*.

37. Radius-Rod Hanger-Pin.—The pin used to connect a straight type of radius-rod hanger to the arm of the reverse-shaft crank is shown in Fig. 17 (*c*). The tapered end of the pin is held in the arm of the crank between the collar *a* and the nut at the right. The hanger swings on the straight section of the pin between the collar *a* and the nut and washer *b*. The collar, made with the pin, prevents the pin from being pulled through the crank arm, and it also brings the hanger in line with the center piece in the link.

REVERSE-SHAFT CRANK AND REVERSE-SHAFT ARM

38. Purpose.—The purpose of the reverse-shaft crank *7*, Fig. 18, is to transmit the movement of the reach rod *17* to the reverse shaft *6* and to the radius-rod hanger on the right side of the engine. The purpose of the reverse-shaft arm *8* is to transmit the movement of the reverse shaft to the radius-rod hanger on the left side of the engine.

39. Construction.—The type of reverse-shaft crank used depends largely on the method used to connect the crank to the radius rod. The type of crank shown in Fig. 18 is used when the radius-rod hanger is a straight bar as shown. The reverse-shaft crank in this case is held on the reverse shaft by a $\frac{5}{8}$-inch square key, the end of which is shown. The key is the same length as the width of the crank at the reverse shaft. The reach rod *17* is connected to the vertical arm *7′* of the reverse-shaft crank, by a pin *n*, which has to be applied from the outside because the reach rod lies too close to the boiler to permit it to be applied from the inside. A case-hardened bushing is pressed into the reverse-shaft crank arm *7′* where the reach-rod pin passes through. The assembly of the reverse-shaft arm *8* on the reverse shaft *6* is similar to that of the reverse-shaft crank. In some cases a bolt which passes entirely through the reverse-shaft crank and the reverse shaft, is used to hold the crank on the shaft, and a similar arrangement is used with the reverse-shaft arm. The arrangement must be such as to prevent the crank from turning on the shaft.

40. Another type of reverse-shaft crank used when the rear end of the radius bar slides in a block, is shown in Fig. 4.

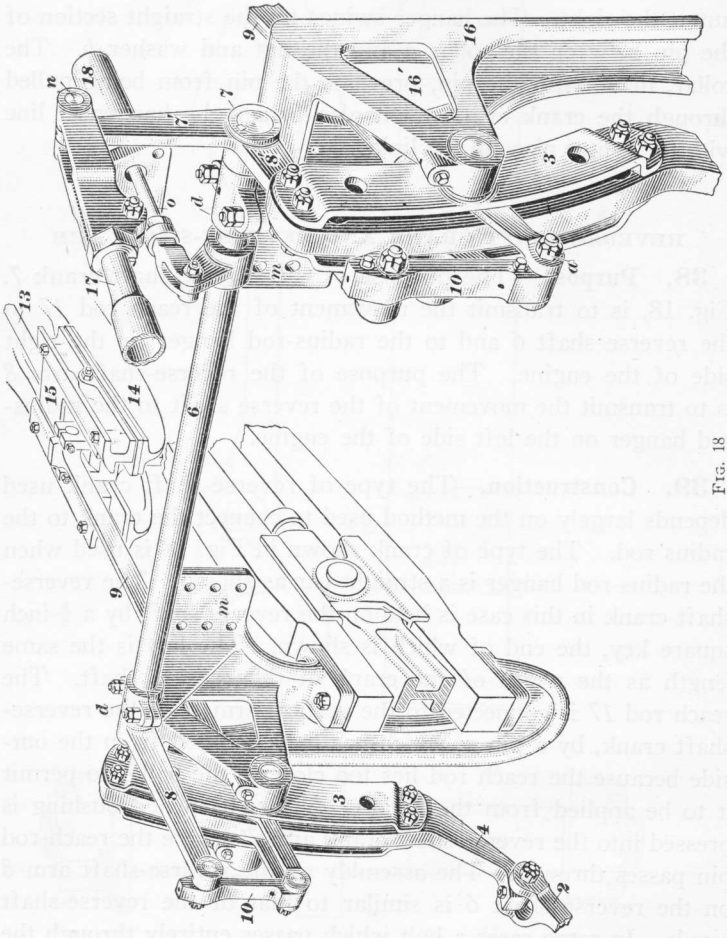

Fig. 18

The part of the crank next to the radius rod is forked and consists of an outer and inner arm *8'*, one on each side of the

radius-bar lifter *10*. The arm *7'* is a single shaft, connected to the reach rod *17* by the pin shown. The crank is keyed to the end of the reverse shaft as in Fig. 18, and case-hardened bushings are pressed into the arms *8'* for the radius-rod lifter trunnions *c*. The reverse-shaft arm on the other end of the reverse shaft *6* is similar to the reverse-shaft crank except that the arm *7'* is not used. The arm is keyed to the reverse shaft similar to the reverse-shaft crank. In some cases the outer arm *8'* of the reverse-shaft crank is made separate from the inner arm, and the two are connected at the reverse shaft by studs. This arrangement makes it easier to apply the radius-bar lifter, as it can be assembled in the arms in one piece.

The reverse-shaft cranks in Figs. 1 and 2 are similar to the one shown in Fig. 18, except that the arm *7* to which the reach rod connects, points downwards.

REVERSE SHAFT

41. Purpose.—The purpose of the reverse shaft *6*, Fig. 18, is to transmit the movement of the reverse lever to the valve gear on the other side of the engine. The shaft is carried in boxes *d* on the top of the gear frame *16*.

ASSEMBLY OF PARTS

42. Assembling Link.—The manner in which the link is placed in the gear frame depends on the construction of the frame. When the gear frame is made in one piece, as in Fig. 18, the link has to be assembled in it one part at a time, but with a built-up type of frame, Fig. 2, the complete link, if desired, can be placed in the frame before it is bolted together; if not, the link has to be applied in the same way as with a one-piece gear frame. The application of the link to a one-piece gear frame is as follows:

The trunnion *b*, Fig. 9, of one of the cheek pieces of the link is first placed in its bearing in the gear frame. The other cheek piece is next placed beside the first one and moved sideways until its trunnion enters the bearing in the other side of

the frame. The center piece *c* with the link block assembled in it is then placed between the two cheek pieces, and the cheek pieces and the center piece are bolted together. There is sufficient room to place one cheek piece in position after the other one has been applied, because the length of a link trunnion is less than the width of the center piece.

Bearing boxes of the type shown at each end of the reverse shaft, Fig. 18, are sometimes used to carry the link trunnions, and the link can then be applied to the gear frame, assembled. Solid bearings, however, are preferable whenever they can be used, because there are no studs or nuts to work loose.

43. Assembling Radius Rod in Link.—The manner in which the radius rod is assembled in the link depends on whether the rod is made in one or two pieces. In Fig. 4 the rear end of the radius rod *9* slides in the radius-rod lifter *10*, and with this construction the rod must be made in two parts in order to assemble it in the link. To place the rod in the link, the two parts are separated by removing the three bolts *k*. The rear end *a'* of the rod is placed in the lifter and pushed up as far as possible and the link is swung far enough forwards to permit the forked end of the rod to be inserted through the link. The rod is raised or lowered in the link, whichever is more convenient, until the link-block pinhole in the rod comes opposite the holes *a'*, Fig. 9, in the cheek pieces. The link block is next raised until the hole in the link block also lines up with the holes in the cheek pieces and in the rod. The link-block pin *h*, Fig. 13, is then driven through from the inside of the link until it is flush with the side of the rod and the pins *i*, one in each jaw, are driven down to keep the link-block pin from turning. The pins *i* are split and spread slightly at their lower ends to prevent them from working up. The assembly is completed by bolting the two parts of the radius rod together.

44. In order to insure that the pins *i* strike the slots *i'*, Fig. 13 (*b*), when the link-block pins are driven down, the proper position of the pin in the rod to bring the slots and the holes in the rod in line is indicated by a mark *f'*, Fig. 4, on the end of the pin and the side of the rod. With the two marks in

line, the pins can be driven down without trouble. When the rear end of the radius rod *9* is carried on a hanger *10* as in Fig. 18, the rod does not have to be made in two pieces in order to assemble it in the link. The rod is placed in the link by removing the pin *a* and passing the forked end of the rod backwards through the opening *16'* in the gear frame. The link block is connected with the radius rod, as already explained, that is, the link-block pin is inserted in the link through one of the circular holes in the inside-bracket piece and the tapered pins that hold the link-block pin from turning are driven down. The back end of the rod is then connected to the radius-rod hanger *10*.

It is not always necessary to assemble the link in the gear frame before assembling the radius rod in it. If desired, the cheek pieces can be placed in the gear frame, as already described. The center piece and the link block are then placed in the forked end of the rod and the link-block pin driven in and pinned, to prevent turning. Then the center piece with the radius rod and link block is raised to position and bolted to the cheek pieces.

45. Assembling Radius-Bar Lifter.—The radius-bar lifter *10*, Fig. 4, is made in four pieces, two side pieces *b*, each with a trunnion *c*, and a top and bottom plate *a* of brass, the parts being held together by four bolts. The trunnions *c* are carried in case-hardened bearings pressed into the arms *8'* of the reverse-shaft crank. When the link swings, the back end of the radius bar moves back and forth in the lifter and because the end of the rod swings in an arc, the lifter turns slightly on the trunnions *c*. Liners are provided between the parts *a* and *b* which are removed and replaced by thinner ones when the top and bottom pieces *a* wear. The oil cup with a screw-cap on the upper plate *a* is packed with hair, and oil is applied through the hole in the top of the cap. The oil grooves in the top of the radius rod serve to retain the oil. The wearing faces of the plates *a* are also supplied with oil grooves.

The radius-bar lifter is assembled in the arms of the reverse-shaft crank one part at a time. With one of the side pieces *b*

in position, the other is placed beside it and moved sideways, until its trunnion enters fully the bearing in the arm. The top and bottom plates *a* are then bolted on. This type of lifter, on account of the number of wearing parts, is troublesome to maintain. A better design of radius-bar lifter when a cradle type of gear frame is used, is shown in Fig. 2.

46. Arrangement and Assembly of Combination Lever and Valve-Stem Crosshead.—In Fig. 19 (*a*) is shown the valve-

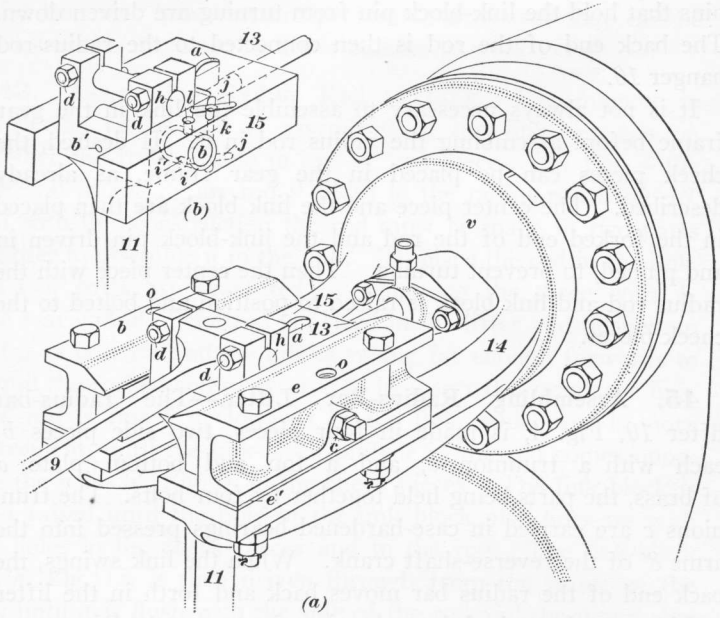

FIG. 19

stem crosshead *15* connected to the combination lever *11*, assembled in the crosshead guide *14*. View (*b*) shows the crosshead *15* removed from the guide with parts of the valve stem *13* and combination lever connected to it. The purpose of the valve-stem crosshead and guide bars *b* and *e* is to guide the movement of the valve stem and keep it central with the valve chamber. They also carry or support the combination lever and the parts connected with it.

In Fig. 19 (*a*) the valve-stem crosshead guide *14* is cast in one piece with the steam-chest head *v* of the valve chamber and the guide bars *b* and *e* are secured to the guide by four bolts. Brass liners *e'* are placed under each guide-bar and permit the guides to be closed when they wear. The valve-stem crosshead *15* which is connected to the valve stem *13* by the key *a* is oiled through oil cups screwed into the oil holes *o*, view (*a*). The setscrew *c* in the side of the outer guide bar, when screwed in, forces the valve-stem crosshead against the opposite guide bar and keeps it from moving. This screw, which has a locknut next to the guide bar, is only used when a breakdown in the valve gear or engine requires that the valve be held in a fixed position.

47. The combination lever *11*, Fig. 91, (*b*), is connected to the valve-stem crosshead guide *15* by the pin *b*, the ends of which turn in case-hardened bearings *i* in the guide. The bearings are pressed into the guide and are prevented from turning by round dowel pins *i* driven below the surface, and the hole burred over. The pin *b* is prevented from turning in the combination lever and the wear on the pin, therefore, is confined to the ends by a $\frac{1}{2}$-inch tapered pin *b'* which passes entirely through the lever as shown in Figs. *14* and *15*, and either engages a slot in the side of the pin, or passes through its center. The pin is applied from the front through the valve-stem hole in the crosshead so that it cannot work out when the valve stem is connected, and it is also riveted over on the outer end.

48. The oil grooves *j*, Fig. 19 (*b*), in the top of the crosshead serve to retain the oil, and they are connected through the oil hole *k* to similar grooves in the bottom face of the crosshead. The oil feeds to the oil grooves from the oil cups on the oil holes *o*, view (*a*). The ends of the pin *b* are oiled through the oil holes *l* direct, or indirectly through the oil holes *o* in the guides, in Fig. 19 (*a*). The combination lever is connected to the valve-stem crosshead as shown in (*b*) before the crosshead is placed in the guides and connected to the valve stem. The combination lever, view (*b*), is placed in the crosshead through the slot in the rear, and the pin *b* is driven through until the

ends are flush with the sides of the crosshead. The pin *b'* is next driven in from the front through the valve-stem hole and the outer end is riveted over. Then the crosshead is placed in the guides *e*, view (*a*), and is moved forwards on to the end of the valve stem, and the key *a* driven down. The radius rod *9* is connected to the combination lever by placing it between the jaws of the lever, then driving in the pin *h*, and tightening the nuts on the binding bolts *d*. In some cases the crosshead is lightened by drilling four holes in its lengthwise, two at the front and two at the rear.

49. Other Arrangements of Valve-Stem Crosshead and Guides.—There are two general arrangements of valve-stem crossheads and guides, one as shown in Fig. 19, in which the guide is cast in one piece with the back-steam chest head, and the other as shown in Fig. 20, in which the crosshead *a* slides on a guide bar *b*. The type shown in Fig. 19 is in more general use because the guide does not have to be lined up with the center of the valve chamber when assembling as with the type shown in Fig. 20. The upper end of the combination lever is forked to span over the valve-stem crosshead to which it is flexibly connected by the pin *e*. The valve stem *d* is held in the crosshead by a nut *d'* on the rear end, and by the key *k*.

The crosshead is made in two pieces, the part *a* which slides on the top and sides of the guide bar and the part *a'* which wears on the under side of the bar. The two parts are connected by three bolts *c* with the nuts on the inside. The wearing surfaces of the part *a* are lined with brass or some other suitable bearing material.

50. The combination-lever pin is oiled through the oil cup *f*, Fig. 20, and the guide bar through the oil cup *f'* which has a hinged cover. These cups are packed with waste or hair so that the oil feed will be gradual. The front end of the guide bar is bolted to a lug on the back steam-chest head and the back end to a lug on the main guide yoke. The guide bar *b* is supplied with oil grooves *h*, and oil holes *h'* are drilled all the way through and connect with oil grooves on the under side, similar to the grooves *n*. The purpose of the oil holes and the oil

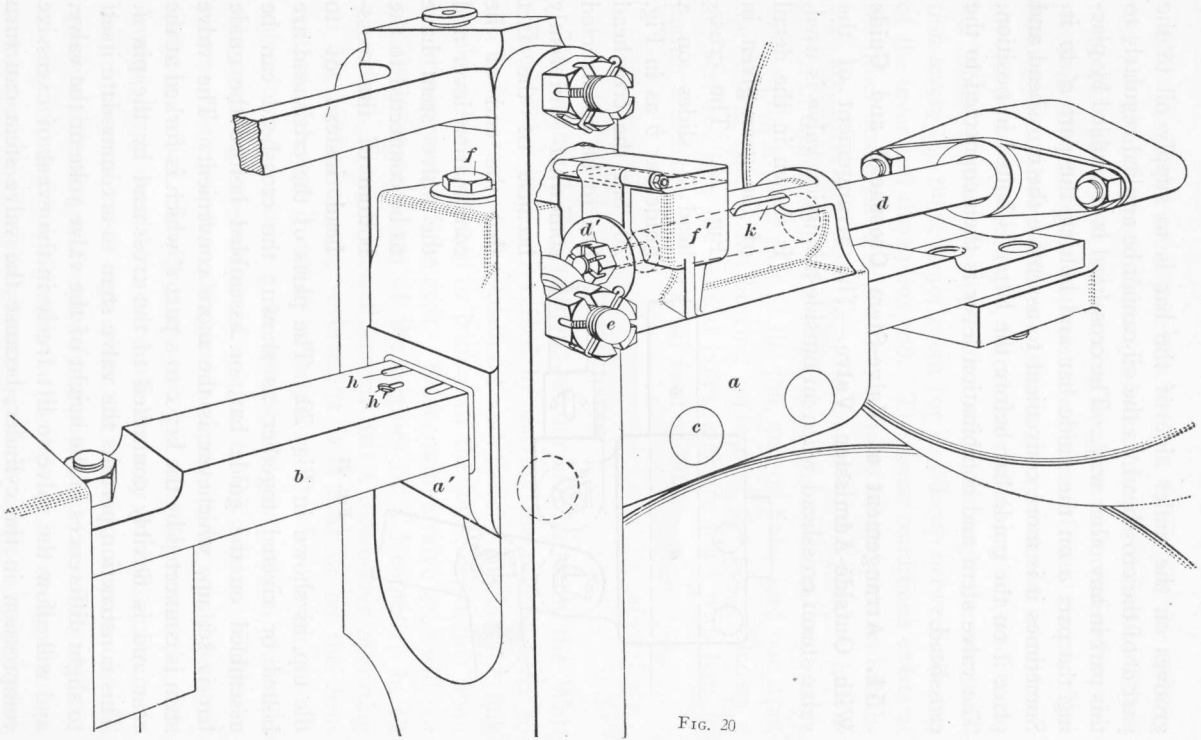

FIG. 20

grooves on the under side of the bar is to supply oil to the part a' of the crosshead, as the oil cannot be applied regularly to this part in any other way. The crosshead is assembled by placing the part a on the guide bar and bolting the part a' to it. Sometimes it is more convenient to assemble the crosshead and place it on the guide bar before the latter is bolted in position. The valve stem and combination lever is then connected to the crosshead.

51. Arrangement of Valve-Stem Crosshead and Guide With Outside-Admission Valve.—The arrangement of the valve-steam crosshead when an outside-admission valve is used, is shown in the detail of the gear given in Fig. 21. The crosshead a slides on a guide bar b as in Fig. 20, but the crosshead has to be constructed somewhat differently because of the fact that the end of the combination lever and the valve stem have to be connected to the bottom of the crosshead instead of to the top, as shown in Fig. 20. The parts of the crosshead are bolted or riveted together as shown; the crosshead can be assembled on the guide bar, or assembled before the guide bar is set up, whichever is the more convenient. The valve stem is connected by the key c to a part c' which is forked at the rear and is flexibly connected to the crosshead by the pin d. This construction permits the valve stem to accommodate itself to slight differences in the height of the valve yoke or the valve, and will allow the valve to lift freely in the event of excessive compression in the cylinder, because the valve stem can turn freely on the pin d.

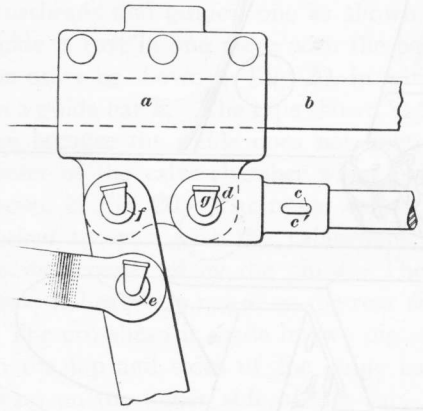

FIG. 21

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52. As is the usual practice, the pin *d*, Fig. 21, the radius-rod pin *e*, and the combination-lever pin *f* are fixed in their respective parts and the wearing surfaces are confined to the portions of the pins between the jaws of the parts. The arrangement shown will not permit the pins to be oiled from the outside. For example, to oil the radius-rod pin and bushing would require the application of oil through the combination lever, and there is not room for an oil cup between the top of the lever and the radius rod. The same conditions exists at the other bearings. The wearing surfaces of the pins and bushings are, therefore, oiled from the center of the pins. A hole is drilled into the center of each pin from the outer end and passes through the greater part of the pin, and oil holes lead out from the central hole to the bearing surface of the pin. Elbows *g* are screwed into the central holes, and are filled with hair to permit a constant and gradual feed of oil.

REVERSING

53. General Explanation.—A locomotive with the Walschaert valve gear is reversed by moving the reverse lever to the back corner of the quadrant and thereby placing the link blocks either in the top or bottom of the links, depending upon the arrangement of the gear. A locomotive valve gear will not positively reverse one of the engines of a locomotive in all positions. Thus, it is well known that a locomotive operating on one side cannot be reversed if it is near or on the dead centers, although it can be reversed in all other positions. In order for a locomotive to be reversed in any position, the main pins must be one-quarter of a turn, or 90°, apart. With the pins more or less than this amount apart, there would be positions in which the locomotive could not be reversed. The reverse lever must be moved all the way in the quadrant to insure reversal, and even then the starting impulse in the opposite direction is frequently imparted to one side only, the starting impulse varying with the position of the main pins. In certain positions the slack has to be taken so as to obtain a more advantageous position from which to start the train.

54. Principle Involved.—The principal involved in the reversing of an engine will be explained by referring to Fig. 22. With the main pin *c* on the bottom quarter and the eccentric crankpin *b* on the back dead center, the engine can be made to run backwards by moving the pin *b* to the front dead center at *b'*. The reason is that this condition places the eccentric crank the same amount ahead of the main pin when running backwards as forwards, and opens the back steam port the same amount as the front port was opened before reversal.

55. The following fundamental principle can be derived from the foregoing: Reversal of motion requires eccentrics, or an effect equivalent to eccentrics at the same distance from the main pins, when moving backwards as when moving forwards. All locomotive valve gears are designed to conform to

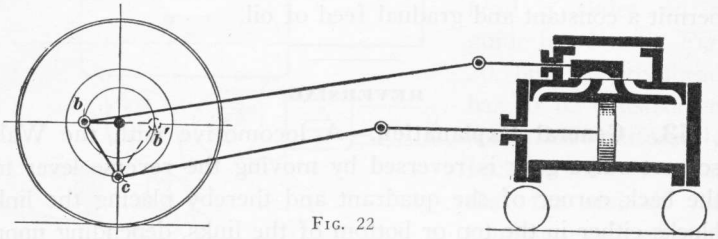

FIG. 22

this principle when the reverse lever is moved from either corner of the quadrant to the other. With the Stephenson valve gear the back-up eccentric meets the requirement of an eccentric the same distance from the main pin when running backwards as when running forwards. With the Walschaert gear and but one eccentric crank, an effect is produced equivalent to changing the position of the crank one-half of a turn when the radius rod is moved from one end of the link to the other. Thus, although the eccentric crank is fixed, it can be considered as occupying the same position with respect to the main pin when the locomotive is running backwards as when it is running forwards. The effect of eccentric cranks at the same distance from the main pins when moving back as when moving ahead, places the valves in the proper position and also gives them the proper movement for the reverse direction.

56. Movement of Valves When Reversing.—The action equivalent to giving the eccentric cranks one-half of a turn when reversing with the Walschaert valve gear causes a certain definite movement of the valves. The valves will so move that steam will be admitted to the opposite end of one or both cylinders, depending on the position of the main pins, and the movement of the valves will be such when the engine starts as to keep it moving in the reverse direction. As already stated, the movement of the radius rods from the bottom to the top of the links has the same effect as giving the eccentric cranks one-half turn on the main pins. It will be found more convenient at first when studying the effect on the valves when a locomotive is reversed, to consider the movement of the eccentric cranks through one-half turn instead of shifting the reverse lever and radius rods.

57. In Fig. 23 (*a*) is shown the position of the valve gear when the main pin on the left side is on the top quarter, and view (*b*) shows its position on the right side with the main pin on the forward dead center. The valve gear on the right side will be considered first. If the eccentric crankpin is moved from *a* on the top quarter to the bottom quarter *a'* or one-half of a turn, the valve will be in the same position with the front steam port open the amount of the lead as shown. When the engine starts backwards, the valve moves ahead, or the movement is such as to keep the engine moving in the reverse direction. The same movement will be imparted to the valve if the radius rod *9* is moved to the position shown by dotted lines to the upper part of the link. However, as the steam is admitted to the same end of the cylinder, it is evident that the starting impulse backwards must be obtained from the left side.

In view (*b*) the back steam port is opened fully, as the eccentric crankpin *a* is on the back dead center. If the eccentric crank is given a one-half turn and moved to *a'* on the front dead center, the valve will be moved to close the back steam port and open the front steam port an equal amount. Therefore, steam is admitted to the opposite end of the cylinder and the driving wheel will turn backwards. The valve when the

engine starts will also move in the proper direction to keep the engine running backwards, that is, the valve will move back preparatory to opening the back steam port the amount of the lead when the piston reaches the back end of the cylinder.

The same effect is produced by moving the reverse lever and placing the radius bar in the top of the link. With the eccentric crankpin at *a* the link is inclined as shown, and the lower end is moved to its extreme position backwards and the upper

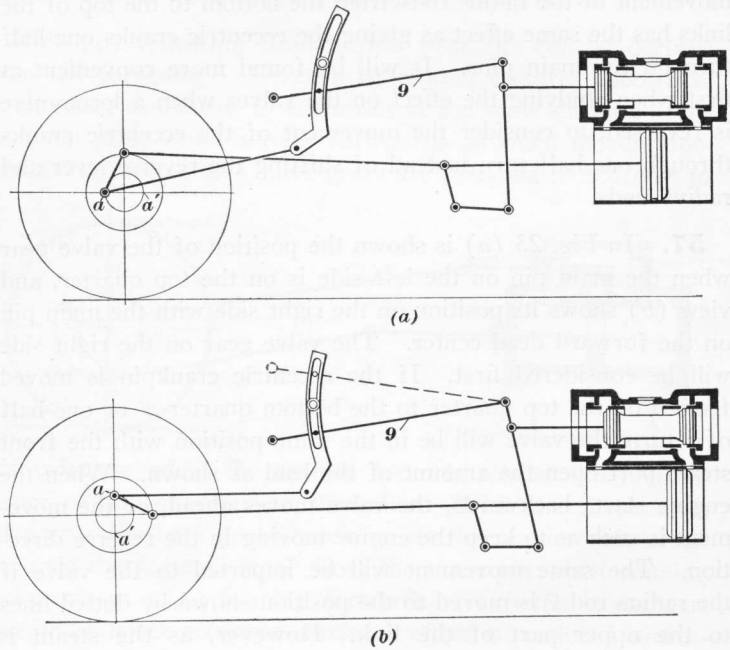

FIG. 23

end to its extreme position forwards. The radius rod when raised, will move ahead and the valve will be moved the same amount ahead of the center of the link trunnions as it was behind them before reversal. The valve then shifts the steam from the back end to the front end of the cylinder.

58. The more the links are inclined, the greater will be the horizontal movement of the radius rods and hence of the

valves when the reverse lever is changed; and the less their inclination, the less will be the valve movement. The maximum and the minimum movements of the valve when a locomotive is reversed occur when the main pin on one side is on either dead center and the pin on the other side is, therefore, on the top or the bottom quarter.

In Fig. 23 (*a*) the valve on the left side opens the opposite steam port fully because the link is at its greatest inclination, on account of the eccentric crankpin being on the dead center.

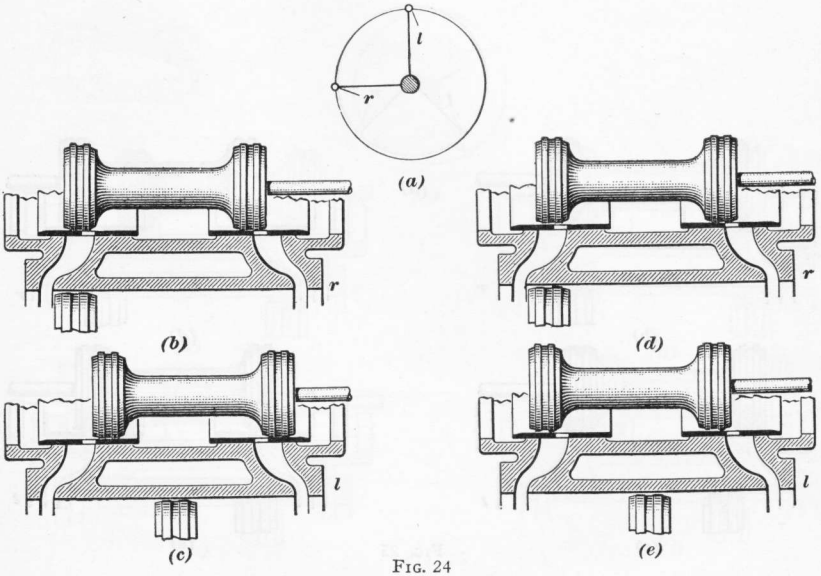

FIG. 24

In view (*b*) the valve does not move because the eccentric crankpin is on the quarter and the link is in central position.

The foregoing can be summarized as follows: To reverse a locomotive it is necessary merely to produce an effect equivalent to placing the eccentric cranks in the same position relative to the main pins when running in one direction as in the other, for the reason that this action not only causes the valves to admit steam to the opposite end of one or both cylinders, but also gives the valves the proper movement to keep the locomotive moving. The valve movement depends on the position of the

main crankpins, and is greatest with the pins on the quarters and the least on the centers.

59. As already stated, the amount that the valves will move when the engine is reversed will vary with each position of the eccentric crankpins and of the main crankpins. On account of practically the infinite number of positions in which the main crankpins can be placed, it is impossible to study the valve movement in all positions. However, in Figs. 24, 25,

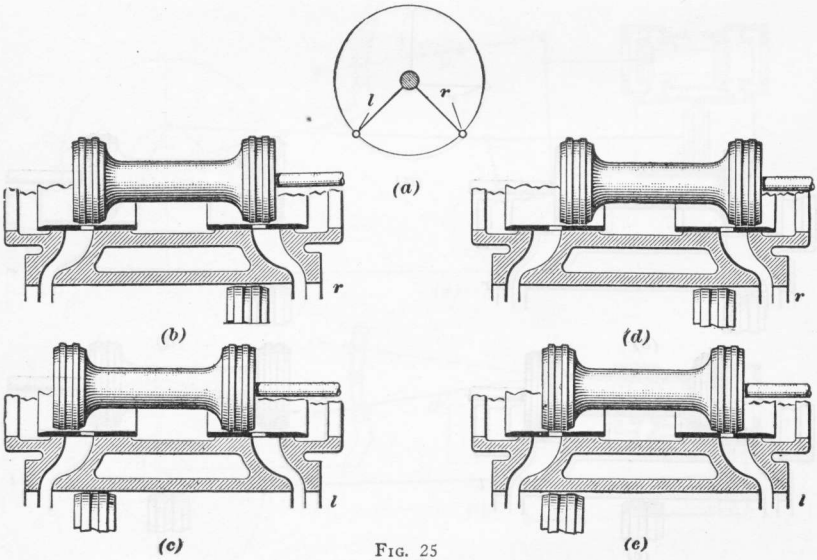

FIG. 25

26, and 27 are shown the change in the position of the valves when the engine is reversed with the main pins in certain representative positions.

In Figs. 24, 25, 26, and 27 is shown the movement of inside-admission valves when a locomotive is reversed, with the main crankpins in different positions. The positions of the main crankpins are shown in view (*a*), the position of the valve before reversal in views (*b*) and (*c*), and their position after reversal in views (*d*) and (*e*). The crankpins and the cylinders on the left side are marked *l*, and on the right side they

are marked *r*. As shown by the valve stems, the front of the engine points to the left.

It is assumed that the reverse lever is in full forward gear before reversal, and that it is in full backward gear after reversal. The lever is usually moved all the way back when reversing so that the maximum valve movement and the greatest port opening possible will be obtained. With the main crankpins in the position shown in Fig. 24 (*a*), the valve on the right side, view (*b*), has the front steam port open the

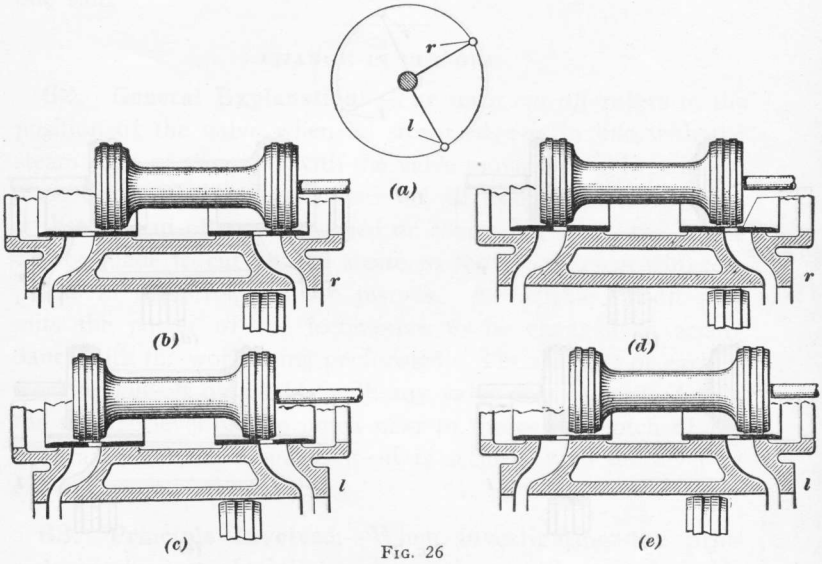

FIG. 26

amount of the lead, and the valve on the left side, view (*c*), has the back steam port wide open. The position of the valves is, therefore, the same as shown in Fig. 23. When the locomotive is reversed, the valve on the right side, view (*d*), does not change its position. The valve on the left side, view (*e*), opens the front steam port the same amount as the back port before reversal. In this case the locomotive for the instant starts backwards from the left side.

60. The valve movement during reversal with the main pins as shown in Fig. 25, view (*a*), is as follows: The valve on

the right side, view (*b*), is at cut-off at the front steam port, and the front steam port on the left side, view (*c*), is fully open. When the locomotive is reversed the valve on the right side, view (*d*), opens the back steam port fully and the valve on the left side, view (*e*), moves to cut-off at the back steam port. In this instance the locomotive starts backwards from the right side.

With the crankpins in the position shown in Fig. 26 (*a*), the valve on the right side has the back steam port opened fully

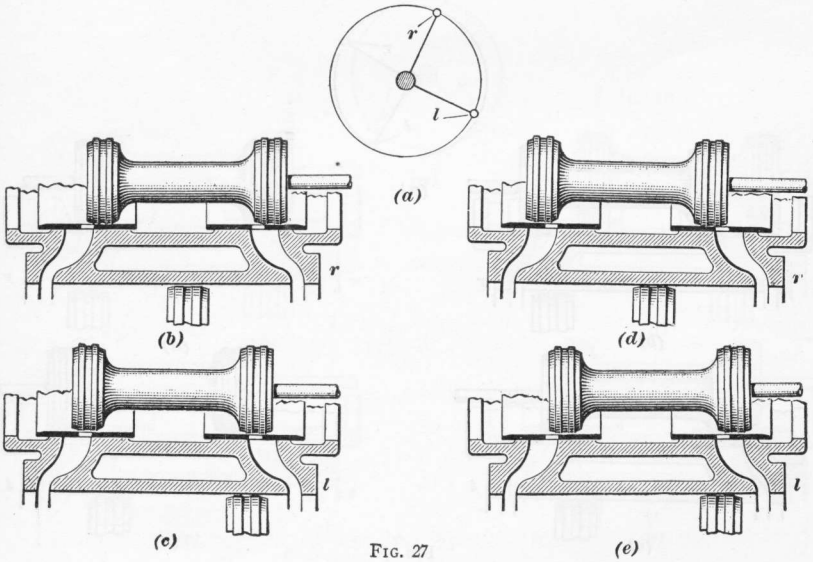

FIG. 27

and the valve on the left side, view (*c*), is about at cut-off at the front port. When the locomotive is reversed, the valve on the right side moves to cut-off at the front port. The valve on the left side opens the back port fully and the locomotive starts back from this side.

61. With the crankpins in the positions shown in Fig. 27 (*a*), the valve on the right side, view (*b*), has the back steam port opened wide, and the valve on the left side is about to open the front steam port to exhaust. When the locomotive is reversed, the valve on the right side, view (*d*), moves so as to

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open partly the front steam port, and the valve on the left side, view (*e*), opens the back steam port fully. Therefore, the locomotive starts backwards from both sides. The foregoing shows that the locomotive when reversed usually receives a starting impulse backwards from one side. Generally a locomotive starts backwards from both sides when one crankpin is near the dead center, as shown in Fig. 27. With both the pins some distance above or below the dead-center positions, the movement in the reverse direction is generally received on one side.

CHANGE IN CUT-OFF

62. General Explanation.—The term *cut-off* refers to the position of the valve when its steam edge is in line with the steam edge of the port, with the valve moving in a direction to close the port. A characteristic of all locomotive valve gears is that the cut-off can be varied or changed, that is, the valves can be made to cut off the steam to the cylinders at different points in the stroke of the pistons. A variable cut-off permits the power of the locomotive to be changed in accordance with the work being performed. The shortest or earliest working cut-off obtainable with any valve gear is secured with the reverse lever in the notch next to the center notch of the quadrant, and the longest cut-off is secured with the lever in either corner of the quadrant.

63. Principle Involved.—When investigating the principle involved in obtaining a change in cut-off, it is desirable to consider an arrangement of parts simpler than a valve gear, but one that will impart practically the same movement to the valve. An arrangement of this kind is shown in Fig. 28 in which *a b* is the main crank and *b c* the eccentric crank. The angle of advance *l b c* is the angle through which the eccentric crank has been turned in order to bring the valve to the point of admission with the main pin at *a*. The circles shown are described by the main pin *a* and the eccentric crankpin *c* when the wheel *d* turns. The valve is assumed to be at the point of admission with the pin *c* at the point shown, hence the valve

will be in exactly the same position when c has turned to f which is opposite c. However, with the pin at f, while the valve is in the same position as at c, it is moving in the opposite direction and is, therefore, at cut-off. The point e on the main crank will move through an arc $e\,g$ on the eccentric crankpin circle equal to the arc $c\,f$, and this brings the main pin at h when the cut-off takes place. If the point c is now moved

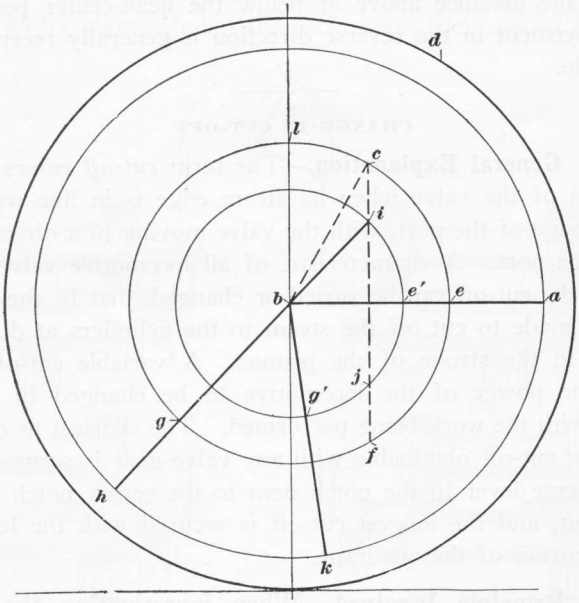

FIG. 28

to i, the valve will be at cut-off with the eccentric crankpin at j and the main crankpin at k, because the point e' will move through an arc $e'\,g'$, equal to the arc $i\,j$.

The reason for the cut-off occurring earlier with the eccentric crankpin at i than at c is that moving the pin to i increases the angle of advance of the eccentric crank from $l\,b\,c$ to $l\,b\,i$ or by an amount equal to the angle $c\,b\,i$, and decreases the throw of the crank from $b\,c$ to $b\,i$. Decreasing the angle of advance brings the eccentric crank $b\,i$ closer to the main crank $a\,b$ and, therefore, the two cranks will not move so far

before cut-off takes place. Moving the point *c* to *i* gives the same effect as moving the link block nearer to the center of the link.

64. The following fundamental principle can be derived from the foregoing. A variable cut-off is obtained by producing an effect equivalent to changing the throw and the angular advance of a single eccentric. The development of all locomotive valve gears can be traced back to a single shifting eccentric such as is shown in Fig. 28, and the action of the combined movement of the eccentric crank and the combination lever is similar to that of a single shifting eccentric. Therefore, the reason for a decreased cut-off with the valve gear is that bringing the link blocks nearer to the middle of the links has the same effect as if the valves were operated by eccentrics of a decreased throw and an increased angle of advance.

BACK-SET OF LINK FOOT

65. Angularity of Eccentric Rod.—The angularity of the eccentric rod affects the movement of the link foot and, therefore, of the valve in the same way that the angularity of the main rod influences the movement of the piston. This means that the link foot will not be midway between its extreme forward and backward positions with the eccentric crankpin on the quarters, halfway between dead centers. As a result, the valve will not move an equal distance on each side of its mid-position and the cut-off will not occur at the same point in the stroke for one stroke of the piston as the other unless a correction is introduced.

Thus, in Fig. 29 (*a*) when the eccentric crankpin moves from the forward dead center *a* to the bottom quarter at *b*, the bottom of the link foot, unless arranged differently than shown, will move from *c* to *d* which exceeds the movement from *d* to *e* through which the foot passes while the crankpin moves from the bottom quarter to the back dead center at *f*. In order to move the valve an equal amount on each side of mid-position and thereby make the cut-off equal at each end

of the cylinder, it is necessary for the link-foot pin to move through the same space while moving from its extreme position forward at *c* to its central position *d*, as when moving from *d* to its extreme position backwards at *e*. The link-foot pin is

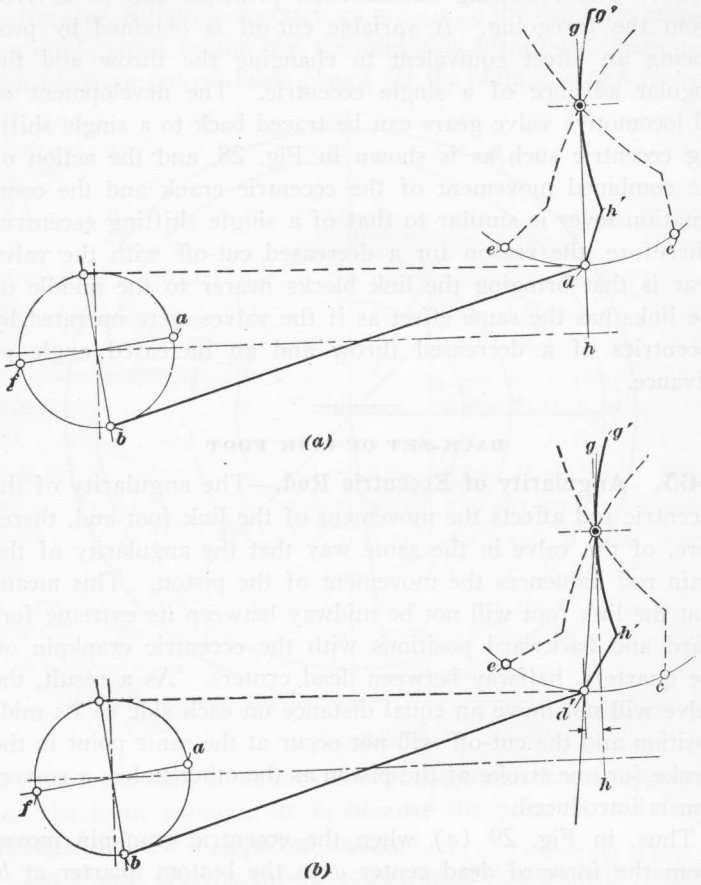

FIG. 29

made to swing through an equal arc on each side of its central position and, thereby, equalizes the movement of the valve, by moving the link foot to the rear, or back-setting it.

66. Effect of Back-Setting Link Foot.—In Fig. 29 (*a*) the link foot is not backset because the line *g h* tangent to or

touching the link arc $g' h'$ with the link in central position passes through the center of the link-foot pin d. Fig. 29 (b) shows the link $g' h'$ in central position as before, but with the link foot moved behind the line $g h$ to d'. It might seem that setting the link foot back would merely decrease the forward swing by the amount of the back-set and increase the backward swing by the same amount, and thereby leave the condition the same as before. However, this is not the case, for while the forward swing of the link foot is restricted to an extent practically equal to the amount of the back-set, yet the backward movement is increased in excess of the backset. The reason is that the back-set causes the link foot to rise higher, and hence, for a given movement of the eccentric crank, the link foot moves in a longer arc when the foot swings to the rear than when it swings to the front.

The result with the proper amount of back-set is that the arcs $c d'$ and $d' e$ become equal and the link foot and the valve will move the same distance on each side of their center positions. The exact amount of the back-set is obtained by trial when designing the gear, that is the point d' is moved backwards until it swings as far to the rear of its central position as it does in front of it.

An error is sometimes made in stating that the link foot is back-set to correct the angularity of the main rod. With a main rod 10 feet long, and a stroke of 28 inches, the error due to the angularity of the rod is only $\frac{3}{4}$ inch, and hence does not have to be considered.

BREAKDOWNS

67. Obtaining Valve Movement When Gear Fails.—The fact that the valve obtains its movement from two different points makes it possible to retain one source of movement when a failure of a part of the gear destroys the other source of movement. Thus, when the movement of the eccentric crank cannot be transmitted to the valve on account of the fact that the eccentric crank, the eccentric rod or the link foot breaks, the gear can be arranged to retain the lap-and-

lead movement. However, it is not generally practicable to obtain the valve movement from the eccentric crank in the event of a failure of the combination lever or the union link.

68. Broken Eccentric Crank, Eccentric Rod, or Link Foot. If the eccentric crank, eccentric rod, or link foot breaks, no valve movement can be obtained from the eccentric crank, and the gear should be arranged after the broken parts have been removed so as to retain the valve movement desired from the combination lever. This can be done by disconnecting or removing the radius-rod hanger shown in Fig. 30, and blocking the radius rod so as to place the link block in the middle

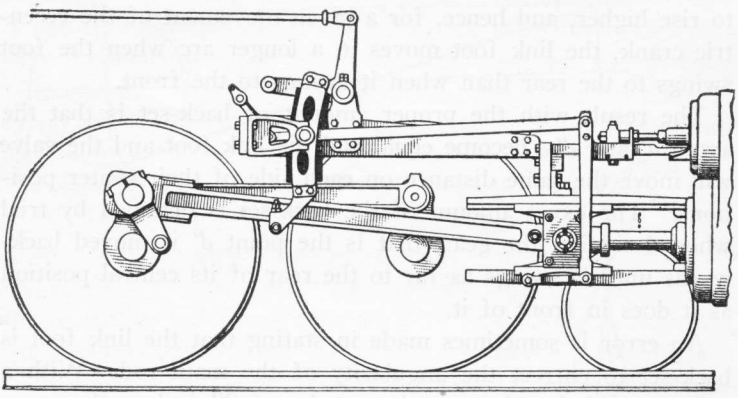

FIG. 30

of the link. To remove the radius-rod hanger pins without damaging the ends, the nuts should be removed, and the side of the radius rod and the reverse shaft close to the pins should be struck with a hammer when the pins will drop out. To secure the link block in the proper position, the radius rod should be placed in the middle of the link and pieces of wood shown in black in Fig. 30 should be driven between the center piece and one of the bracket pieces of the link. The space at this point is about $1\frac{9}{16}$ inches wide. When the radius rod is blocked in this position, the link-block pin and the link trunnions are in line, so that the rod will remain fixed and its front end will act as a fulcrum point for the combination lever

the same as when the reverse lever is in mid-gear. The combination lever then imparts the usual travel to the valve or a movement equal to twice the lap and twice the lead for each stroke of the piston.

69. The amount of steam admitted to the cylinder does not help the movement of the piston materially because the maximum port opening or the lead, which is about $\frac{1}{4}$ inch, occurs with the piston at the beginning of the stroke, and the valve begins to close the port as soon as the piston begins to move. However, the steam lubricates the piston and the cylinder. The locomotive should be stopped on the working side with the pin on the quarter, because if stopped on the center, the valve on the partly disabled side will be in mid-position and the locomotive cannot be started unless the combination lever is disconnected at the lower end and the valve moved in the proper direction. If the back end of the radius rod is carried in a slip block, as shown in Fig. 4, the block will have to be removed by taking out the four bolts shown, before the radius rod can be blocked in the link.

The eccentric rod is the part of the valve gear that usually breaks and the failure usually occurs where the forked front end is welded to the rod. Another cause of failure of the eccentric rod is that the nuts work loose on the eccentric-rod pin, and that the pin works out and strikes the main rod.

70. Broken Radius Rod.—A broken radius rod prevents any movement from being transmitted to the valve by the eccentric crank or the combination lever. The procedure to follow depends on whether the break requires or does not require the rod to be taken down. If the break is near the front end, the rod will not have to be removed, and the broken end can be chained up. The valve-stem crosshead guide should be pulled to a position that will cause the valve to open the back steam port slightly so that enough steam will enter the cylinder to lubricate the piston. Then the stud *c*, Fig. 19, should be screwed in to hold the crosshead fixed. If the cylinder can be lubricated through the indicator-plug openings, the valve can be secured in mid-position, if so desired.

If, as is sometimes the case, the rules of the road will not permit any movement of the valve gear when a part is disabled, the eccentric rod and the radius-rod hanger must be taken down. The union link, too, must be disconnected from the crosshead arm and secured so that the crosshead cannot strike the combination lever. The eccentric rod can be taken down by first removing the eccentric-rod pin at the front end, and then removing the nut and washer, *d* and *e*, Fig. 7, if this style is used; or the nut *e*, Fig. 6, on the inside of the crank arm, and then driving the pin *c* out if this arrangement is used.

71. If the break in the rod requires it to be taken down, and if the rod is made in one piece, the procedure is as follows: With a ½-inch bolt, the two tapered pins *i*, Fig. 13 (*a*), that hold the link-block pin in the radius rod, should be driven up. The link hanger *10* should be disconnected and the rod lowered or raised, as the case may be, until the link-block pin *h* comes opposite the circular holes in the bracket pieces in the link. Then a bolt should be placed in the hole in the outer bracket piece against the end of the pin, which should be driven out. The radius rod can now be removed by pulling it forwards.

If the rod is made in two pieces as in Fig. 4, the two parts should be disconnected by removing the bolts *k* and driving out the tapered pins *i* and the link-block pin *h* should be driven out as before. Then the rod should be pushed back into the slip block, Fig. 4, as far as possible and the front end swung down until it clears the link. The rod can now be pulled out of the slip block. If the link is not in the proper position, it may be necessary to disconnect the eccentric rod in order that the bottom of the link can be swung far enough ahead to clear the end of the radius rod while it is being moved down and back. The front part of the rod can now be removed from the combination lever by taking out the radius-rod pin.

72. Broken Combination Lever or Union Link.—A failure of the combination lever or union link is liable to lead to serious consequences because the valve stops moving, and

should it stop in a position to trap steam in the cylinder, the compression may become high enough to blow out a cylinder head, bend the main rod, or even demolish the cylinder saddle. The nuts on the pins in the ends of the union link, as well as the nut on the radius-rod pin, should be inspected frequently to see that they are not working off. If the union link fails, and there is no further damage, the broken parts should be removed, and the bottom end of the combination lever tied forward to the cylinder cock, Fig. 31, so that the crosshead will not strike. Then the radius rod should be disconnected from the top of the combination lever and tied up. When the combination lever breaks, the lower part can be easily

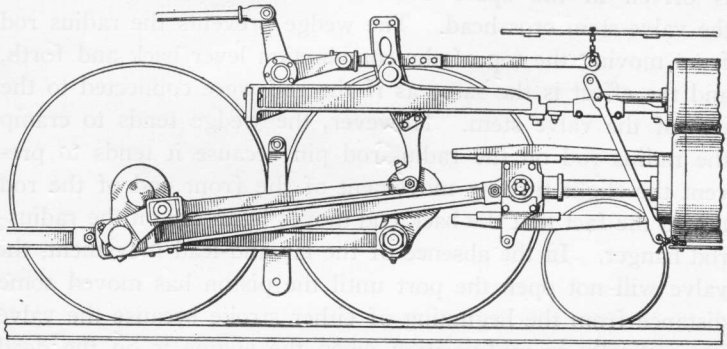

FIG. 31

removed by disconnecting the union link from the crosshead arm or the wristpin. The arrangement of the upper end of the lever at the valve-stem crosshead, as explained in Art. **29.** makes it difficult to remove this part of the rod, and the best way is to tie it out of the way after the radius rod has been disconnected. To disconnect the combination lever from the valve-stem crosshead with the arrangement shown in Fig. 19, which is the one usually met with, requires considerable time. The valve stem must be disconnected from the crosshead by driving out the key *a* and the crosshead must be removed from the guides in order to remove the pin *b'* and the crosshead pin *b*. The crosshead must then be replaced and connected to the valve stem in order to hold the valve.

73. If it is absolutely necessary to take down the combination lever, the quickest way is to remove the valve-stem crosshead with it. The valve-stem key should be driven out, the lever and the crosshead removed at the same time, and left connected. The valve-stem crosshead cannot then be used to hold the valve, but an inside-admission valve is so nearly balanced, that a thin wooden wedge driven in between the valve stem and the gland will hold the valve in position. It is possible, although not generally practicable, to transmit the movement of the eccentric crank to the valve when the combination lever breaks. If the break is close to the valve-stem crosshead guide, the radius rod is left connected and a wedge is driven in the space between the front of the rod and the valve-stem crosshead. The wedge prevents the radius rod from moving the top of the combination lever back and forth, and the effect is the same as if the rod were connected to the end of the valve stem. However, the wedge tends to cramp the radius rod on the radius-rod pin because it tends to prevent the slight turning movement of the front end of the rod due to the fact that the back end moves in an arc on the radius-rod hanger. In the absence of the lap-and-lead movement, the valve will not open the port until the piston has moved some distance from the beginning of either stroke because the valve is practically in mid-position when the engine is on the dead center.

74. Broken Radius-Rod Hanger or Pins.—A broken radius-rod hanger or hanger pins prevents the radius rod from being moved by the reverse lever. If the rod hanger or one of the pins breaks, the broken parts should be removed and the link block secured in the link in the proper position to give the required cut-off. This can be done by driving wooden blocks between the center piece of the link and one of the bracket pieces as explained in Art. **68.** A small space should be left between the blocking and the rod because the rod has a slight up-and-down movement when the link swings. The same procedure should be followed if the arm of the reverse-shaft crank, to which the rod hanger is connected, should

break. Care should be taken not to reverse the engine, because the valve gear on the disabled side will remain in forward gear and the gear on the other side will move to backward gear.

If the arrangement is similar to that shown in Fig. 4 and a failure occurs at lifter *10*, the arms *8'*, or the back end of the radius rod, the rod can be disconnected from the lifter by removing the four bolts shown. This permits the removal of the top and bottom plates, and the radius rod will drop down. The parts *b* can then be moved sideways and taken out of the arms *8'*. The link block can then be secured as just described.

WALSCHAERT VALVE GEAR

(PART 2)

Serial 4003B Edition 1

EXAMINATION QUESTIONS

Notice to Students.—*Study the Instruction Paper thoroughly before you attempt to answer these questions.* **Read each question carefully and be sure you understand it;** *then write the best answer you can. When your answers are completed, examine them closely and correct all the errors you can find; then mail your work to us.*

(1) How is the pin that connects the combination lever to the valve-stem crosshead prevented from turning in the lever?

(2) What should be done if the radius-rod hanger breaks?

(3) In what positions of the main pins does the locomotive generally start backwards from both sides?

(4) What is the purpose of the gear frame?

(5) What should be done if the radius rod breaks?

(6) What is the purpose of the link?

(7) Why is a failure of the union link liable to lead to serious consequences?

(8) What is the purpose of the eccentric crank?

(9) Explain the valve movement that occurs when the locomotive is reversed with the right side on the forward dead center?

(10) How is the link-block pin prevented from turning in the radius rod?

(11) What should be done if the eccentric crank, eccentric rod, or link foot breaks?

(12) Explain the reason for using different types of gear frames.

(13) What is the purpose of the radius rod?

(14) What should be done if the combination lever or union link breaks?

(15) How is the eccentric crank held on the main pin?

(16) What is the purpose of the reverse shaft?

(17) Explain how to take down a radius rod.

(18) With the main pins in the positions given in Fig. 24, from what side of the locomotive does the starting impulse backwards come?

(19) What is the purpose of the eccentric rod?

(20) What is the purpose of the combination lever?

Mail your work on this lesson as soon as you have finished it and looked it over carefully. DO NOT HOLD IT until another lesson is ready.

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